Fall 2015

The Effects of an Isometric Quarter Squat on Countermovement Jump Performance

Mitchell W. Dropp
Western Washingtn University, droppm@students.wwu.edu

The Effects of an Isometric Quarter Squat on Countermovement Jump Performance

By

Mitchell Dropp

Accepted in Partial Completion

of the Requirements of the Degree

Master of Science

Kathleen L. Kitto, Dean of the Graduate School

ADVISOR COMMITTEE

Chair, Dr. Dave Suprak

Dr. Lorrie Brilla

Dr. Gordon Chalmers

MASTERS THESIS

In presenting this thesis in partial fulfillment of the requirements for my master's degree at Western Washington University, I grant to Western Washington University the non-exclusive royalty-free right to archive, reproduce, distribute, and display the thesis in any and all forms, including electronic format, via any digital library mechanism maintained by WWU.

I represent and warrant this is my original work, and does not infringe violate any rights of others. I warrant that I have obtained written permission from the owners of any third party copyrighted material included in these files.

I acknowledge that I retain ownership rights to the copyright of this work, including but not limited to the right to use all or part of this work in future works, such as articles or books.

Library users are granted permission for individual, research and non-commercial reproduction of this work for educational purposes only. Any further digital posting of this document requires specific permission from the author.

Any copying or publication of this thesis for commercial purposes, or for financial gain, is not allowed without my written permission.

Signature: Mitchell W. Dropp

Date: January 17, 2016

The Effects of an Isometric Quarter Squat on Countermovement Jump Performance

A Thesis

Presented to

The Faculty of

Western Washington University

Accepted in Partial Completion

of the Requirements of the Degree

Master of Science

Mitchell W. Dropp

December, 2015

Abstract

The purpose of the study was to determine if an isometric quarter squat was sufficient to elicit postactivation potentiation (PAP) in a countermovement jump (CMJ) for recreationally trained individuals (n = 22). The isometric quarter squat conditioning stimulus consisted of three sets of six second maximal voluntary contractions against a custom made apparatus. The conditioning stimulus was designed to acutely enhance CMJ performance by stimulating PAP, in turn improving indicators of CMJ performance which included eccentric rate of force development (ERFD), mean rate of force development (MRFD), peak rate of force development (PRFD), reactive strength index (RSI), and peak power (PP). CMJ performance was tested at one, five, ten, and fifteen minutes post-conditioning stimulus to identify the optimal recovery time for optimal performance. Statistical analysis was carried out using a two-way repeated measures analysis of variance (ANOVA) and no significant or meaningful change was found in ERFD, MRFD, PRFD, RSI, or PP. The overall power was small for all variables suggesting that the ability of the current study to observe an effect that might have existed was very unlikely. Effect size was also small in all variables suggesting that the change pre to post-testing was not meaningful. Some critical factors that may have contributed to the results included the individual's ability to potentiate, body positioning during conditioning stimulus, and level of conditioning of subjects.

Acknowledgements

I would like to thank Western Washington University for the higher education I received through the program. A special thank you to the faculty that I have been privileged to work, learn, and grow with in the Department of Health and Human Development.

Thank you to Dr. Gordon Chalmers for your invaluable thoughts of my work. Your constant effort in driving my critical thinking of not only others but work my own work has been instrumental in my development and growth as a professional. Thank you to Dr. Lorrie Brilla for supporting me through my many years in the program. I cannot thank you enough for your words of wisdom and your ability to spark creativity and imagination in my work. A very deserving thank you goes to Dr. Dave Suprak for supporting me though the struggles and accomplishments of my projects. Without your passion, dedication, and support none of this would have been possible.

I would like to thank my close friends who were there as a great support system as I was going through the program. You all hold my highest level of appreciation and respect. Last, I would like to thank my family for giving me much needed guidance, support, and inspiration over the years. Your never ending love and support continues to be one of the greatest driving forces in my life.

Table of Contents

CHAPTER IV RESULTS AND DISCUSSION

List of Tables

List of Appendices

Chapter I

The Problem and Its Scope

Introduction

Training modalities that maximize performance for power athletes are desirable in the athletic community. Differences in medal rankings are marginal for athletes that participate in explosive types of movements and activities that require high levels of strength and power, such as Olympic weightlifting. Therefore, any training modality or performance preparations that aid in maximizing performance, even by a very small margin, can be highly desirable. Postactivation potentiation (PAP) is a phenomenon involving enhanced contractile force and power properties of muscle following a high intensity muscle action. The enhancement of the contractile properties of skeletal muscle through PAP is one mechanism that could have practical applications, especially in events that require rapid rates of force development and high levels of muscle activity. While a number of studies have successfully elicited PAP, the overall mechanism(s) and variables that allow for PAP to occur have not been conclusively determined.

There are many theories that aim to explain the mechanism(s) of PAP including increased motor neuron activity (Hamada, Sale, MacDougall, & Tarnopolsky, 2000; O'Leary et al., 1997), increased reflex activity (Folland, Wakamatsu, & Fimland, 2008; Garner, Hicks, & McComas, 1989), enhanced muscular blood flow (Garner et al., 1989; Mangus et al., 2006), and increased myosin regulatory light chain (RLC) phosphorylation (Gallagher, Herring, & Stull, 1997; Gordon et al., 2000; Moore & Stull, 1984; O'Leary et al., 1997; Stull et al., 2011; Szczesna et al., 2002; Zhi et al., 2005). Currently, there is limited research supporting mechanisms for PAP taking place outside of muscle (motor neuron activity, reflex activity, and muscular blood flow).

On the other hand, there is a substantial amount of research supporting both directly and indirectly that PAP exists as an intramuscular phenomenon via RLC phosphorylation. While the supporting evidence for RLC phosphorylation does suggest that this may be a primary mechanism for PAP, it does not suggest it is the only mechanism.

There are multiple variables that effect the extent of PAP manifestation, including muscle temperature (Close and Hoh, 1968; Moore & Stull, 1984; O'leary et al., 1997; Rassier & MacIntosh, 2000), fatigue (French, Kraemer & Cooke 2003; Garner et al., 1989; Gossen & Sale, 2000; Kilduff et al., 2007; O'leary et al., 1997; Rassier & MacIntosh, 2000), level of training (Brandanburg, 2005; French et al., 2003; Gossen & Sale, 2000; Hilfiker et al., 2007; Kilduff et al., 2007; Smith & Fry, 2007; Till & Cooke, 2009), and muscle fiber type distribution (Hamada et al., 2000; Moore and Stull, 1984; Smith & Fry, 2007; Yetter & Moir, 2008). In addition, there are multiple variables that can be manipulated to elicit PAP, including the intensity and duration of the conditioning stimulus, the resting interval between the conditioning stimulus and potentiated exercises, and the type of conditioning stimulus. The most common protocol for PAP consists of a dynamic or biomechanically similar activity used to potentiate a following activity. This usually consists of a high intensity multi-joint exercise, such as a back squat. The potentiated exercise typically consists of an explosive or plyometric movement, such as a countermovement jump.

Biomechanically similar conditioning stimuli have been suggested to elicit PAP, and have been used in research to elicit PAP, however it is not clear whether this protocol is necessary. While it is necessary to potentiate the musculature that is used in the potentiated exercise, it is not clear whether it is necessary to make the conditioning stimulus biomechanically similar. Research suggests that the intensity of the conditioning stimulus is,

instead, one of the major variables that should be considered and not the muscle action. Further research is necessary to determine if a biomechanically similar (muscle action type) conditioning stimulus is necessary (Baudry & Duchateau, 2004; Gullich & Schmidtbleicher, 1996).

There are multiple studies that have used biomechanically similar conditioning stimuli to elicit PAP in both the type of activity and muscle action. However, some evidence suggests that a maximal muscle contraction and the activation of the maximal number of muscle fibers may be a more important variable for eliciting PAP than its similarity of the conditioning stimulus to the potentiated exercise (Baudry & Duchateau, 2004; Gullich & Schmidtbleicher, 1996). A maximal isometric contraction is a type of exercise that can allow for complete activation of muscle groups from a fixed muscle length. Based on previous results, this may be all that is necessary for the proper activation of PAP (Baudry & Duchateau, 2004; Gullich & Schmidtbleicher, 1996).

Purpose of the Study

The current study aimed to determine if an isometric quarter squat that activates similar musculature but is not biomechanically similar to a countermovement jump (CMJ) was sufficient to elicit PAP in a CMJ. Indicators of PAP included eccentric rate of force development (ERFD), mean rate of force development (MRFD), peak rate of force development (PRFD), reactive strength index (RSI), and peak power (PP).

Experimental Hypothesis

The null hypothesis states that a conditioning stimulus consisting of 3 sets of 6-second isometric back squat will not elicit PAP in a CMJ in recreationally trained individuals.

Significance of the Study

There is a large body of research that has been done on the variables that affect the extent to which a high-force conditioning stimulus is able to potentiate a subsequent high-power movement. This study further investigates the type of conditioning stimulus that can be used to potentiate a CMJ. In addition, it will determine if potentiation can take place from a maximal isometric contraction instead of an exercise that mimics the activity being potentiated (CMJ). The current study aims to determine if eliciting PAP is a much simpler task than previously suggested. In this case, PAP would require little to no equipment and this procedure could be used by a wider range of athletes in a variety of settings.

Limitations of the Study

1. The results of the study may only be applicable to the specific population that was studied.
2. Subject adherence to the program was an important part of the study. Therefore, adherence was controlled through constant subject researcher communication using e-mail. Subjects were excluded from the study if they were not able to adhere to the testing protocol.
3. A number of variables were not controlled or measured in the study, including intramuscular temperature, muscle length, and muscle fiber type distribution. However, the subjects were tested in the same facility using a consistent procedure.
4. Specific environmental factors may affect PAP, including temperature and humidity. To control for this, the experimental tests took place at the same location at a similar temperature.

5. While PAP was tested in the study using force platform data, the likely mechanisms by which this process occurred were not explored.
6. There may have been variations in exercise habits between subjects. To account for this, exercise habits were documented for further analysis.
7. Improper use of the equipment through operator error may have contributed to the results of the study. To control for this, all equipment was operated by one investigator and a standardized protocol was followed for all participants.

Definition of Terms

Absolute Strength – A measurement of muscular strength with no relation to body weight (Zatsiorsky & Kraemer, 2006)

Complex Training – The combination of high intensity resistance training followed by plyometric exercises within the same training session (Ebben & Watts, 1998)

Conditioning Stimulus – An exercise of varying intensity from moderate to high that is used to potentiate subsequent activities (Wilson et al., 2013)

Eccentric Rate of Force Development (ERFD) – The differences between vGRF when COM velocity equals zero from $vGRF_{min,}$ divided by the time duration (Laffaye & Wagner, 2013)

Ground Reaction Force (GRF) – The corresponding force equal to the sum of forces applied to a surface (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2004)

Mean Rate of Force Development (MRFD) – The difference between the minimum and maximum vertical GRF (VGRF) divided by the time from minimum and maximum VGRF (McLellan, Lovell, & Gass, 2011)

Peak Power (PP) – The maximum power (force x velocity) during the countermovement jump (McLellan et al., 2011).

Peak Rate of Force Development (PRFD) – The maximum change in force over a 10-millisecond time intervals during the countermovement jump (Bompa & Haff, 2009)

Postactivation Potentiation (PAP) – A phenomenon that enhances the contractile force properties of muscle following a high intensity muscular contraction or conditioning stimulus (Gilbert & Lees, 2005)

Rate of Force Development – The change in force over a given time period (Bompa & Haff, 2009)

Reactive Strength Index (RSI) – A quantitative number used to estimate strength and is defined as jump height (meters) divided by time (seconds) to takeoff (Zatsiorsky & Kraemer, 2006)

Relative Strength – A measurement of muscular strength in relation to body weight (Zatsiorsky & Kraemer, 2006)

Twitch Potentiation – The increase in twitch force amplitude following a maximal tetanic muscle contraction (Stull, Kamm & Vandenboom, 2011)

Vertical Countermovement Jump (CMJ) – A pre-stretch followed by a vertical jump that incorporates the stretch shortening cycle (Baechle & Earle, 2008)

Chapter II

Review of the Literature

Introduction

Postactivation potentiation is a unique characteristic of skeletal muscle that allows for an individual to develop higher levels of muscular force following a high intensity conditioning stimulus (Gilbert & Lees, 2005). The following section explores the likely mechanisms of PAP and in turn discusses its possible application to countermovement jump (CMJ) performance. In order to elicit PAP, it is necessary to understand why this phenomenon takes place and what influences its optimal expression. The possible mechanism(s) of PAP are explored thoroughly in the following section. Once a sound physiological basis for PAP is established, appropriate guidelines are discussed in developing a research based conditioning stimuli with appropriate rest intervals to enhance CMJ performance.

Twitch Potentiation and its relation to Postactivation Potentiation

Postactivation is a process which likely involves mechanisms that result in altered contractile properties of muscle for a limited period of time (Moore and Stull, 1984; Palmer & Moore, 1989; Rassier & MacIntosh, 2000; Smith & Fry, 2007; Stull et al., 2011; Szczesna et al, 2002). While PAP has been implemented in training programs often in the form of complex training (Comyns, Harrison, Hennessy, & Jensen, 2006b; Ebben & Watts, 1998; French et al., 2003), there has been very little consistency in the procedures used to elicit PAP (Rassier & MacIntosh, 2000; Robbins, 2005; Stull et al., 2011). In addition, there is a lack of consistency in standardizing and measuring variables that affect PAP (Rassier & MacIntosh, 2000; Robbins, 2005; Stull et al., 2011). The ultimate objective of PAP is to maximize force production in

athletes and competitors; however, more information is needed to determine the most effective protocol for eliciting potentiation.

Guidelines for these parameters have been explored in animal (Close & Hoh, 1968; Moore and Stull, 1984; Palmer & Moore, 1989; Szczesna et al., 2002) and human (Baudry & Duchateau, 2007a; Baudry & Duchateau, 2007b; Brandanburg, 2005; French et al., 2003; Garner et al., 1989; Garner et al., 1989; Gilbert & Lees, 2005; Gossen & Sale, 2000; Hamanda et al., 2000; Kilduff et al., 2007) studies, both in vivo (Baudry & Duchateau, 2007b; Moore and Stull, 1984; O'leary et al., 1997; Palmer & Moore, 1989; Zhi et al., 2005), and in vitro (Close & Hoh, 1968; Szczesna et al, 2002) under multiple experimental designs and subject populations for the most effective protocol.

Twitch potentiation (TP) is classically seen in the literature as a method for eliciting PAP. TP commonly involves a single muscle and can be tested through voluntarily muscle action or electrical stimulation of an innervating nerve (Baudry & Duchateau, 2007a; Baudry & Duchateau, 2007b; Close and Hoh, 1968; Garner et al., 1989; Gossen & Sale, 2000). There is a substantial amount of literature examining twitch potentiation in mammalian subjects (Close and Hoh, 1968; Garner et al., 1989; Klein et al., 2001; O'leary et al., 1997). Literature on TP has been of great value in expanding knowledge on the possible mechanisms by which PAP takes place. The disadvantage of TP studies are that they offer limited application to actual human movement and performance application due to the high level of control needed in the studies.

Other research has investigated PAP using a larger scale, multi-faceted approach. PAP commonly, but not always, involves muscles or muscle groups used for increased performance outcomes in elite or recreationally trained athletes (Brandanburg, 2005; French et al., 2003; Gilbert & Lees, 2005; Hilfiker et al., 2007; Kilduff et al., 2007; Scott & Docherty, 2004; Smilios

et al., 2005). For the purpose of this review, it is assumed that TP is one mechanism for eliciting PAP. Both TP and PAP studies were used throughout the current review section to determine the variables and mechanisms that drive and manipulate PAP.

History of Twitch Potentiation

PAP has been observed in vitro in mammalian skeletal muscle under controlled condition for over 60 years (Brown & von Euler, 1938; Close & Hoh, 1968). While this is by no means the first study to examine PAP in skeletal muscle, Close and Hoh (1968) give historical perspective to an observation suggesting that repetitive electrical stimulation of skeletal muscles in mammals results in altered and enhanced muscle contractile properties. Using extensor digitorum longus muscles from four week old female rats, Close and Hoh (1968) surgically extracted and electrically stimulated rat muscle fibers under controlled conditions (optimal muscle length and regulated temperature) and measured force output using a tension transducer. By stimulating the skeletal muscle at a specific amplitude and frequency in a pretest, potentiation, posttest fashion, it was found that a high frequency of stimuli results in increased peak tension, increased contraction time, increased half relaxation time and increased twitch duration. The discovery of this phenomenon (muscle contraction followed by altered muscle contractile properties) has since been followed by a flood of research that aimed to determine both the mechanism and application of PAP (Robbins, 2005).

Possible Mechanisms of Postactivation Potentiation

There are multiple theories that have aimed to explain the mechanism of PAP in skeletal muscle. These mechanisms include increased motor neuron activity, increased reflex activity, enhanced muscular blood flow, and increased RLC phosphorylation. However, very few have a substantial body of knowledge to support their claims. For the purpose of this review, the

possible mechanisms of TP can be divided into two general categories; potentiation that takes place as a result of physiological changes within or outside of skeletal muscle cells. Motor neuron activity, reflex activity, and enhanced muscular blood flow fall under the category of extracellular mechanisms, while RLC phosphorylation is considered an intracellular mechanism.

Extracellular Mechanisms

Augmented Neuronal Activity. One proposed mechanism for PAP has been suggested to be due to augmented neuronal activity. Klein, Ivanova, Rice, and Garland (2001) explored the relationship between changes in motor unit discharge rate and twitch force in the triceps brachii muscle in an attempt to better understand twitch potentiation. In this study, six subjects were seated with an arm placed in a U-shaped brace mounted on a force transducer to measure elbow extensor force. Using EMG to measure muscle activity, ramp and hold isometric contractions were performed at 10, 20, and 30% maximum voluntary contraction (MVC) with and without a submaximal conditioning stimulus at 75% 1RM held for 5 seconds. It was determined that the relative increase in twitch force after the conditioning stimulus was inversely correlated ($r = -0.74$, $P < .01$) with the relative decrease in motor unit discharge rate. Decreased neural recruitment suggests that the muscle has become more efficient, allowing the same amount of tension to be held using fewer motor units. In addition, a small number of motor units in four subjects were derecruited following the conditioning stimulus. However, 2-6 minutes later the derecruited motor units became active again to their initial control level, suggesting that increased neural activity does not play a part in PAP and in fact decreases as a result of a conditioning contraction.

Insignificant or no changes in motor neuron activity following a conditioning stimulus have also been substantiated by other authors suggesting that potentiating contractions are

maintained via intracellular sources as opposed to neural augmentation (Baudry & Duchateau, 2007a; Baudry & Duchateau, 2007b; French et al., 2003; Gossen & Sale, 2000; Luca, Foley & Erin, 1996). However, not all studies are in agreement. In a study by Garner, Hicks, and McComas (1989), subjects' feet were strapped to an aluminum plate and muscle stimulation of the ankle dorsiflexors was triggered via the peroneal nerve. Measuring torque of the ankle, two experimental procedures were used and differed only in the presence or absence of ischemia by use of a blood pressure cuff in the leg being investigated. It was determined that an increase in muscle EMG (M-wave) amplitude which is an indication of the level of muscle activity took place following an electrically stimulated tetanic contraction. M-wave amplitude increased slightly until approximately 90 seconds upon which it drastically fell until the cuff was released. While this information is conflicting with the previous studies, the value of M-wave augmentation was relatively small. Other studies have also found increases in M-wave amplitude following a conditioning contraction; however, this was only demonstrated through electrical stimulation of target muscle tissue giving limited application to voluntary muscle action (Hamada et al., 2000; O'leary et al., 1997).

M-wave amplitude changes are rarely supported in the literature. While there is some evidence to suggest that augmented M-wave amplitude may result in PAP, data suggests that neural influences play a very minimal role in PAP (Esformes, Keenan, Moody, & Bampouras, 2011). However, multiple studies investigating M-wave amplitude follow differing protocols, which could account for the inconsistent findings (Baudry & Duchateau, 2007a; Baudry & Duchateau, 2007b; French et al., 2003; Gossen & Sale, 2000; Luca, Foley & Erin, 1996). Therefore, further research with consistent protocols would be needed in order to come to a reasonable conclusion in this matter.

The Hoffman Reflex. Another theory proposed to affect PAP is the augmentation of Ia afferents. One method of studying the Ia afferents is through the Hoffman reflex (H-reflex). The H-reflex consists of electrical stimulation of an afferent nerve in an attempt to estimate alpha motor neuron excitability given presynaptic inhibition (Zehr, 2002) and intrinsic excitability (Capaday, 1997) remain constant. The H-reflex has been suggested to indicate presynaptic and post synaptic modifications of the stretch reflex. The evidence provided by studies employing H-reflex testing supports the hypothesis that PAP could be a result of increased efficiency and/or rate of nerve transmission to skeletal muscle (Palmieri, Ingersoll, & Hoffman, 2004). While this is plausible, there are multiple limitations of H-reflex modifications to PAP. In terms of its relation to actual biological processes, reflex activity is stimulated due to an external source (electrical stimulation) and thus the muscle spindle is bypassed. In turn, bypassing the muscle spindle gives limited insight into voluntary muscle actions and dynamic movements that involve sensory receptors which are vital to movement. There is also no direct communication between Ia afferents and motor neurons (Palmieri et al., 2004). Presynaptic modification plays a large role in motor neuron excitability through both excitatory and inhibitory pathways resulting in varying H-reflex readings (Palmieri et al., 2004). Postsynaptic modifications, in turn, would make it difficult to validate H-reflex sensitivity as a valid measure for changes in PAP. Also, the external environment (e.g. loud and inconsistent noises) and body position can alter H-reflex activity if not under strict control (Palmieri et al., 2004).

Folland et al. (2008) proposed that reflex augmentation may have little influence on voluntary activity and maximal efforts for the H-reflex to activate primarily slow twitch motor units (Buchthal & Schmalbruch, 1970). In terms of the size principle, maximal efforts result in maximally activated slow and fast twitch motor units, thus any reflex stimulation of these motor

units during a maximal voluntary contraction would not contribute to any further muscle activity for altered strength outcomes (Folland et al., 2008).

However, one study found reflex potentiation following a conditioning stimulus. In a study by Folland et al. (2008), careful consideration of proper experimental procedures for H-reflex testing was taken while determining the effects of a conditioning stimulus on H-reflex and PAP. Using eight recreationally active men, percutaneous stimulation of the femoral nerve was used to analyze M-waves and H-reflexes isometrically. From the study, it was determined that there was augmented reflex sensitivity following a 10 second isometric voluntary contraction, however there was no relative changes in strength performance following reflex potentiation. This suggests that a maximal voluntary conditioning stimuli under optimal parameters may enhance the transmission of Ia afferents to alpha motor neurons. It was further suggested that this may either be due to decreased pre-synaptic inhibition or altered neurotransmitter release. However, augmentation did not increase strength performance. Collectively, this information suggests that enhanced reflex sensitivity is not a likely mechanism for PAP during maximal voluntary contractions.

Muscular Blood Flow. Another possible mechanism that could affect PAP outside skeletal muscle cells includes increased muscular blood flow. While increased muscular blood flow following a maximal tetanic contraction has not been experimentally substantiated, a few studies have suggested this as a possible mechanism (Garner et al., 1989; Mangus et al., 2006). In theory, increased blood flow could allow for an increased rate of recovery by delivering vital nutrients and elimination metabolic byproducts. If blood flow does play a part in potentiation, this mechanism would most likely be associated with the level and duration of muscular fatigue along with a decreased duration of compromised force output from muscular fatigue (Garner et

al., 1989; Mangus et al., 2006). However, further research would be necessary to validate this assumption (Garner et al., 1989; Mangus et al., 2006).

To support this idea, a study by Garner et al. (1989) examined the effects of blood pressure cuff occlusion use on the subject's leg during a tonic potentiating electrical stimulus of the tibialis anterior muscle. It was determined that blood pressure cuff occlusion resulted in a decreased M-wave amplitude and twitch torque. However, PAP was still seen between 20-40 seconds independent of cuff occlusion. While this study does not support that increased blood flow can enhance PAP, it does indirectly suggest that the level of blood flow to muscle can affect the magnitude of PAP.

It is important to note that the current review is not suggesting that the previous mechanisms do not play any part in PAP. However, the evidence does suggest that PAP is influenced to a greater degree by other mechanism(s). One mechanism that has been well demonstrated in in the literature to occur in skeletal muscle is the phosphorylation of the myosin regulatory light chain (RLC).

Intracellular Mechanisms

Regulatory Light Chain Phosphorylation and Twitch Potentiation. Of all the physiological mechanisms that aim to explain PAP, RLC phosphorylation is the most widely substantiated. RLC is a small protein subunit that is wrapped around the alpha helical neck region of myosin heavy chain that has been suggested to be important for the structural support of the neck region of myosin (Lowey & Trybus, 2010). Once phosphorylated, it has been suggested that the mechanical properties of RLC are altered resulting in PAP.

Regulatory light chain phosphorylation is a process by which the calcium-calmodulin-myosin light chain kinase complex (Ca^{2+}-CaM- MLCK) phosphorylates the RLC protein and in

turn alters the mechanical properties of the protein (Szczesna et al., 2002). Phosphorylation of RLC does not alter the binding properties of myosin to actin, but instead allows movement of the myosin head out of the resting state in muscle fibers resulting in modulation of calcium-troponin-dependent forces (Stull et al., 2011).

The Ca^{2+}-CaM- MLCK complex is initiated when skeletal muscle is voluntarily or electrically stimulated (Stull et al., 2011). Once a muscle cell reaches its threshold, an action potential depolarizes the cell, releasing calcium from the sarcoplasmic reticulum (Gordon, Homsher, & Regnier, 2000). It is known that calcium is an essential molecule needed for muscle contraction, however there is a collective body of research that suggests that calcium plays another role in skeletal muscle; the regulation of the Ca^{2+}-CaM-MLCK system (Gordon et al., 2000; Szczesna et al., 2002).

When calcium is present in skeletal muscle, it not only binds to troponin for muscle contraction but it also has the ability to bind to calmodulin (Stull et al., 2011). Calmodulin is a molecule that plays a major role in multiple systems including inflammation, metabolism, apoptosis, and muscle contraction of all muscle types (Stull et al., 2011). In the case of skeletal muscle, calcium is necessary for a conformational change in the calmodulin protein allowing it to interact with MLCK. MLCK on its own is inactive due to an autoinhibitory sequence restricting its ability to react with RLC (Padre & Stull, 2000a; Padre & Stull, 2000b). However, MLCK also has a calmodulin binding site but calcium must be bound to calmodulin in order to interact with MLCK. Once Ca^{2+}-CaM binds to MLCK, the newly formed Ca^{2+}-CaM- MLCK complex binds with the N-terminus in RLC at which point an ATP molecule is cleaved, allowing a phosphate to be added to the N-terminus of RLC (Padre & Stull, 2000b). When muscle stimulation ceases, calcium is returned to the sarcoplasmic reticulum and the slow dissociation of

calcium from calmodulin takes place. The dissociation of calcium from calmodulin in turn deactivates MLCK (Stull et al., 2011). At this point, the phosphorylation of RLC ceases and other pathways work to remove phosphate from RLC (Padre & Stull, 2000b; Stull et al., 2011).

It is important to note that calcium, calmodulin, and MLCK can all be rate limiting steps for controlling the amount of RLC phosphorylation that takes place within skeletal muscle (Padre & Stull, 2000b). This means that all three molecules have to be present in order for this process to take place (Padre & Stull, 2000b). Once all three molecules are present, RLC phosphorylation could take place even at low or submaximal contractions, depending on the level of calcium available. Also, it is important to note that the rate of phosphorylation taking place would be limited to the concentration of the Ca^{2+}-CaM- MLCK complex.

The Link between Myosin RLC Phosphorylation and PAP

This overall relation of this myosin RCL phosphorylation to PAP can be explained through a few main processes. Zhi et al. (2005) repetitively stimulated fast twitch skeletal muscle in knockout mice (no MLCK) and in turn found no significant increase in RLC phosphorylation or potentiated twitch forces. On the other hand, wild-type mice displayed isometric twitch potentiation and RLC phosphorylation after a brief potentiating twitch suggesting that Ca^{2+}/calmodulin-dependent MLCK may be the dominant mechanism for potentiation during repetitive stimulation of fast-twitch fibers.

In further support of RLC phosphorylation, the formation of the Ca^{2+}-CaM-MLCK complex and in turn the phosphorylation of RLC is a process that takes longer than a muscle contraction. In the previous study by Moore and Stull (1984), it was determined that phosphorylation took place more slowly than muscle contraction rates during muscle stimulation. In terms of muscle contraction, calcium binding to troponin results in a fast cascade of events

that ultimately results in muscle contraction (Gordon et al., 2000). On the other hand, RLC phosphorylation is the result of a longer process in which calcium dependent proteins (calmodulin and MLCK) follow a large sequence of events resulting in an overall slower process (Moore & Stull, 1984; Stull et al, 2011). This suggests that RLC phosphorylation is present following muscle contraction and continues for some time following muscle relaxation.

Gallagher, Herring, and Stull (1997) explored the properties of MLCK and found that phosphorylation continues for several seconds after relaxation from a brief tetanic contraction; however, the process is slowed due to calcium reuptake. Overall, the formation of Ca^{2+}-CaM-MLCK takes place rapidly but calcium/calmodulin dissociates at a slower rate so the Ca^{2+}-CaM-MLCK continues to phosphorylate RLC. This short-lived potentiating window is consistent with other research determining that potentiation can last for several minutes (Garner et al., 1989). In this sense, RLC phosphorylation could explain why potentiation has a lasting effect between 5-30 minutes, depending on the methods of the study, the characteristics of the individual (e.g. muscle type distribution) and the potentiation process of skeletal muscle (Garner et al., 1989; Hamada et al., 2000; O'Leary, Hope & Sale, 1997).

When considering maximal contractions and the activation of high threshold motor units, RLC phosphorylation is a plausible theory for explaining why there is a slight delay before potentiation occurs. RLC phosphorylation is also a process that may explain why potentiation is prolonged. The mechanism for RLC phosphorylation can also support why a maximal potentiation contraction is necessary for the maximal amount of muscle fibers to be activated (especially the type II muscle fibers) which are likely to have higher levels of MLCK.

The Pathway of Myosin RLC Phosphorylation

The process of RLC phosphorylation is dependent on a number of factors. First, the magnitude of calcium release from the sarcoplasmic reticulum is related to the extent of RLC phosphorylation (Smith & Fry, 2007). RLC phosphorylation is modulated by the interplay between Ca^{2+}-CaM- MLCK complex and myosin phosphatase (Stull et al., 2011). As was stated before, the Ca^{2+}-CaM- MLCK is the complex associated with RLC phosphorylation. However, dephosphorylation does take place. This process is modulated by a protein called myosin phosphatase which acts by detaching phosphates from RLC. Potentiation is able to occur because the activity of the Ca^{2+}-CaM- MLCK molecule interacts with RLC significantly faster than myosin phosphatase. In some cases, it was found that there was a 50 fold difference between the two (Stull et al., 2011). In support of the theory that RLC phosphorylation is a major contributor to TP, Palmer & Moore (1989) found that the rise and fall of RLC phosphorylation was positively correlated to PAP. Given that RCL phosphorylation has an optimum window of activity, it is important to determine the optimal duration through which PAP is expressed.

Consequences of Myosin RLC Phosphorylation

As stated before, RLC is a small protein subunit that has been suggested to be important for the structural support of the neck region of myosin (Lowey & Trybus, 2010). RLC in turn has been suggested to possess characteristics that affect the contractile properties of sarcomeres. The most common theories of RCL phosphorylation suggest myosin heavy chain (MHC) contractile proteins produce more force and develop a higher level of calcium sensitivity in the actin-activated ATPase region of myosin (Szczesna et al., 2002).

In support of this theory, a study by Szczesna et al. (2002) extracted rabbit skeletal muscle and examined the effect of phosphorylated versus non-phosphorylated RLC. The force to

concentration of calcium relationship was determined by mounting muscle fibers on a force transducer and varying concentrations of a purified calcium solution. In addition, RLC was depleted and reconstituted from some skeletal muscles samples for comparison purposes. From the study, it was determined that phosphorylation of the RLC not only increases calcium sensitivity but also raises the maximal steady-state force of isolated rabbit skeletal muscle.

Other authors have suggested that RLC phosphorylation has an effect on maximal velocity of shortening suggesting there is increased level of cross bridge cycling during muscle contraction. In a study by Hamada et al. (2000), 20 recreationally active men were strapped to a seat and tested with a custom made dynamometer to measure isometric torque of the knee extensors. The knee extensors were electrically stimulated via the indirect percutaneous stimulation of the femoral nerve. MVC of the knee extensors were found, followed by a 5 minute wait and then a 10s MVC. At 5 seconds into the MVC, stimulus was applied to assess the extent of motor unit activation (%MUA) according to the interpolated twitch method. Post-MVC twitch responses were evoked immediately (5s) post-MVC, at 30s post-MVC, and at 30s intervals until 5 min post-MVC. EMG, time to peak torque (TPT), and half-relaxation time were measured. Following the testing protocol, subjects with the highest and lowest PAP values had muscle biopsies extracted from the vastus lateralis. One major finding from this study suggested that the time to peak torque TPT after the conditioning stimulus was inversely proportional to PAP ($r = - 0.73$, $P < 0.001$). This research is in support of O'Leary et al. (1997), who found a 13% decrease in twitch rise following a 7 second tetanus contraction.

While intramuscular twitch potentiation has not directly been substantiated in all studies, the overwhelming amount of evidence supports that there are altered contractile properties of

skeletal muscle following RLC phosphorylation. This evidence RLC phosphorylation a very likely contributor to PAP.

Muscle Fiber Type Distribution and Postactivation Potentiation

Other studies have found that type II muscle fibers are better able to potentiate compared to type I fibers. In a study by Moore and Stull (1984), fast and slow twitch muscle fiber were extracted from rats and it was determined that there was more MLCK activity in fast twitch muscle versus slow twitch muscle. In addition, the rate of RLC dephosphorylation was four times faster in slow twitch muscle compared to fast twitch muscle. It was concluded that a greater level of phosphorylation that took place within RLC fast twitch skeletal muscle may have been due to the presence of more MLCK activity and less myosin phosphatase activity. This is in agreement with Hamada et al. (2000), who found that the four highest PAP subjects had more type II muscle fibers compared to the four lowest PAP subjects.

In another study by Yetter and Moir (2008), 10 trained male subjects' sprinting speed was tested following a conditioning stimulus of heavy back squats. It was determined that sprinting speed increased more in the strongest subjects (5.4% change) versus weakest subjects (1.4% change). This information suggests that physically stronger individuals may have a higher PAP potential compared to weaker individuals (Yetter & Moir, 2008).

The volume of data supporting differences in muscle fiber type or muscle strength and PAP suggests that more phosphorylation of the RLC in type II muscle fibers is possible and therefore a higher level of PAP has the potential to occur. In turn, the activation of type II muscle fibers through maximal contraction or twitch stimulation may be necessary to elicit a significant potentiating response.

Duration

Postactivation potentiation has been shown to operate within a specific time domain that can vary considerably due in part to a number of factors, including muscle temperature (Close and Hoh, 1968; Moore & Stull, 1984; O'leary et al., 1997; Rassier & MacIntosh, 2000), fatigue (French et al., 2003; Garner et al., 1989; Gossen & Sale, 2000; Kilduff et al., 2007; O'leary et al., 1997; Rassier & MacIntosh, 2000), level of training (Brandanburg, 2005; French et al., 2003; Gossen & Sale, 2000; Hilfiker et al., 2007; Kilduff et al., 2007; Smith & Fry, 2007; Till & Cooke, 2009), and muscle fiber type distribution (Hamada et al., 2000; Moore and Stull, 1984; Smith & Fry, 2007; Yetter & Moir, 2008). This section will first determine the time periods in which PAP is likely to take place and explore the possible causes that should be controlled to account for this variability.

The duration of PAP has been shown to vary in multiple studies and under varying protocols (Baudry and Duchateau, 2007a; Baudry and Duchanteau, 2007b; Gilbert and Lees, 2005; Kilduff et al., 2007). In a study by Baudry and Duchateau (2007a), 10 subjects between the ages of 24-40 years took part in a study to examine electrically stimulated and voluntary conditioning contractions. This was a very similar study to Baudry and Duchanteau (2007b) with a similar protocol. In both studies, the fatigue resistant adductor pollicis muscle were used with a custom made apparatus. The main finding was a significant enhancement in peak angular velocity of both electrically stimulated and ballistic voluntary contractions of the thumb muscle. There was also an increase in the maximal velocity of shortening and an upward shift in the load-velocity relationship. Duration lasted approximately 5 minutes with the greatest effect happening at 1 minute. At the same time, twitch potentiation declined exponentially over time returning to baseline within 10 minutes of recovery. Overall, these two studies suggest that the modality of

the conditioning contraction (electrical stimulation or voluntary contraction) has the ability to show similar results for potentiation. At the same time, this suggests that PAP can last from 1-10 minutes in fatigue resistant muscles under controlled conditions using a single muscle group.

In another study by Gilbert and Lees (2005), PAP was measured in three protocols using 14 trained male subjects. The conditioning stimulus consisted of 5 sets of 1RM back squat with 5 minutes rest in between, 5 sets of back squats with maximum power and 5 minutes rest in between, and a control with no weight lifted. The vertical countermovement jump (CMJ) performance and an isometric assessment of the quadriceps strength using a custom made apparatus were measured. PAP in the experimental groups was greatest at 20 minutes post conditioning stimulus. On the other hand, the maximum power group displayed optimal potentiation at 2 minutes following the conditioning stimulus and dissipated between 15 and 20 minutes. From this information, PAP in multi-joint activities can range from 2-20 minutes depending on the conditioning stimulus (Gilbert & Lees, 2005).

In another study, 23 professional rugby players were used in order to determine the optimal recovery time for a conditioning stimulus on an explosive activity. The study consisted of two tests of either a high intensity squat or bench press. The protocol consisted of baseline CMJ and ballistic bench press throws, followed by 10 minutes rest. Following the rest period, three repetition maximum (3RM) squats were performed followed by post-testing of 7 CMJ at 15 seconds and every 4 minutes after post stimulus for 20 minutes. The second day followed the same protocol but was replaced with seven ballistic bench throws (40% 1RM on smith machine) and a 3RM bench press. In both the upper and lower body, there was an immediate decrease in power output following a conditioning stimulus. However, PAP was found in upper body peak power output (PPO) at 8-16 minutes (with max of 5% increase at 12 min) and PAP at Lower

body PPO was found from 8-12 minutes (with max of 8% increase at 12 min). These results suggest that rest should be at least 4 minutes to allow for recovery of the phosphocreatine system because fatigue is a likely mechanism immediately post-conditioning stimulus (Kilduff et al., 2007).

Other aforementioned studies have determined that PAP can take place within the suggested time frames through both electrical stimulation (Garner et al., 1989) and voluntary contractions (Smilios et al., 2005; Yetter & Moir, 2008). Collectively, this data suggests that PAP can take place anywhere from 1-20 minutes, depending on the muscle groups that are activated. However, the duration of PAP can vary considerably. For a CMJ in particular, PAP may be seen between 4-12 minutes (Kilduff et al., 2007). Therefore, in order to determine when PAP takes place with a specific conditioning stimulus, it would be important to test the time interval of potentiation within a 1-20 minute time frame. However, for optimal time intervals for PAP to be determined, each testing protocol should be tested for optimal duration periods. While duration is important to PAP, other variables like the intensity of the conditioning stimulus affect PAP potential.

Intensity

The intensity of the conditioning stimulus has also been shown to affect PAP measures. In a study by Gilbert and Lees (2005), three protocols were used and consisted of back squats of either 5 sets of 1RM with 5 minutes rest in between, 5 sets using maximum power with 5 minutes rest in between, or a control consisting of no lifting. Vertical CMJ performance and an isometric knee extension using a custom made apparatus were measured. The control group showed no significant difference in pre to post testing however PAP in the experimental groups was greatest in the 5 set 1RM max group in both rate of force development (11.8%) and CMJ

height (9%), suggesting that intensity may be an important predictor of potentiation (French et al., 2003; Gilbert & Lees, 2005; Hilfiker et al., 2007).

In a study by Yetter and Moir (2008), different conditioning stimuli were tested against average speed during sprinting in 10 trained male subjects. Using a 5 minute warm-up, three conditioning stimulus protocols took place, consisting of heavy back squats, heavy front squats and a control condition. Each protocol consisted of five repetitions of 30%, four repetitions of 50%, and 3 repetitions of 70% with 2 minutes rest in between. Following a 4 minute rest period, 3 sprint trials with 3 minute rest were used to analyze levels of potentiation. From the study, it was determined that the heavy back squat protocol was effective at increasing sprint times at 10-20 meters and 30-40 meters further suggesting that high levels of voluntary muscle (70% 1RM) action may be necessary for PAP. However other studies have found that low to moderate intensity conditioning contractions are sufficient for eliciting PAP (Smilios et al., 2005). Therefore, heavy loads that are close to an individual's 1RM may not be necessary for potentiation.

In a study by Smilios et al. (2005), 10 recreationally trained men with 2-3 years or training experience were used to examine the short term effects of multiple sets of a potentiating exercise on squat jumps (SJ) and CMJ performance. The conditioning contraction consisted of 3 sets of 5 repetitions with 3 minutes rest at 30 or 60% of a 1RM half squat with post testing taking place 1 minute after each set followed by testing at 5 and 10 minutes post-conditioning. Post testing consisted of two squat jumps and two CMJ in succession. It was determined that moderate half squat loads and light to moderate jump squat loads are able to potentiate CMJ height. In addition, one set of a half squat at 60% was sufficient to potentiate a CMJ, suggesting that multiple sets of a conditioning stimulus may not be necessary. The main finding from this

study was that light (30% of 1RM) to moderate (60% of 1RM) conditioning contractions performed at maximal velocity were sufficient at potentiating a CMJ. This suggests that intensity or the intent to move at maximal intensity may be an important variable for eliciting PAP however this was not empirically measured in the aforementioned study.

Heavy loads or moving a lighter weight with maximal speed seem to be a requirement in order to activate all motor units and thus potentiating a larger amount of muscle mass (Smilios et al., 2005). Moving a variety of loads with maximal speed would allow for a maximal amount of calcium to be released from the sarcoplasmic reticulum, thus increasing the potential for RCL phosphorylation to occur. However, high threshold motor units are also highly fatigable, therefore, careful consideration must be made to control for volume so subjects do not become fatigued.

Level of Training

Average or recreationally trained individuals seem to show limited PAP potential in a number of studies (Gossen & Sale, 2000; Mangus et al., 2006; Scott & Docherty, 2004; Smith & Fry, 2007). At the same time, elite or highly trained individuals seem to have a high capacity to potentiate (French et al., 2003; Gilbert & Lees, 2005; Hilfiker et al., 2007; Kilduff et al., 2007; Smilios et al., 2005; Yetter & Moir, 2008). However, this is not always demonstrated in research (Till & Cooke, 2009). The variability in training status and the extent of PAP has been suggested to be due to the level of conditioning that allows elite individuals to have reduced fatigue following an activity and increased recovery rate following a conditioning stimulus (Rassier & MacIntosh, 2000; Tillin & Bishop, 2009). PAP in highly trained and elite athletes may also be due to their overall high level of relative strength compared to non-athletes, which seems to be

an important characteristic of an individual's PAP potential (Hamada et al., 2000; Hilfiker et al., 2007; Yetter & Moir, 2008).

However, one study has found the training status has no influence on PAP finding no statistical change in CMJ height following either one or three 5-second maximal voluntary isometric contractions using a standard inclined (45 degree) leg press machine in power, hypertrophy, in physically active groups (Batista et al., 2011). Instead, five out of ten subjects increased their vertical jumps after the conditioning stimuli irrespective of training status suggesting that PAP may be subject dependent rather than training dependent. While the subjects were encouraged to give maximal effort, one limitation to this study however was that force produced for the conditioning stimuli was not objectively measured therefore it could not be assured that the subjects elicited high levels of muscle activation during the task.

Multiple researchers have determined that PAP may be linked to an individual's training level (Chiu et al., 2003; Esformes et al., 2011; French et al., 2003; Gilbert & Lees, 2005; Hilfiker et al., 2007; Kilduff et al., 2007; Smilios et al., 2005; Yetter & Moir, 2008). However, this could also be due to a number of reasons, including the type of testing protocol, resting duration, the intensity and type of the conditioning stimulus. Therefore, more research with consistent protocols is needed in order to connect training status to PAP.

Fatigue and Optimal Rest

Numerous studies have incorporated resting protocols following a conditioning stimulus in order to optimally to replenish phosphagen stores (Brandenburg, 2005; Kilduff et al., 2007). However, fatigue has also been shown to play a significant role in PAP. In a study by Gossen and Sale (2000), PAP was analyzed on 10 subjects between the ages of 22-35 years. The purpose of the study was to examine the effects of PAP on dynamic knee extension performance using

peak force and maximum unresisted shortening velocity. The conditioning stimulus consisted of a 10 second isometric MVC of the leg extensors. Results from the study indicated that potentiation did not take place following the conditioning stimulus. One of the main reasons that fatigue may have played major a role in the results of the study was because peak torque declined on average 16% during 10 second isometric MVC and peak velocity of first knee extension had decreased following isometric MVC (Gossen & Sale, 2000). Jensen and Ebben (2003), found reductions in vertical jump height at 10 seconds following five repetitions of a 5 RM back squat. Significant reductions in vertical jump flight time has also been observed following at 30 seconds following a similar five repetitions of a 5 RM back squat to the aforementioned study (Comyns et al., 2006b). Fatigue following a conditioning stimulus has also been suggested to have taken place in other studies, especially with the high intensity conditioning contractions (Brandanburg, 2005; Till & Cooke, 2009).

In selecting strategies to take advantage of PAP, careful consideration must take into account both the duration of the potentiating effects of a conditioning stimulus and the fatigue affects generated from the stimulus. A longer recovery following a conditioning stimulus will mitigate fatigue detriments to the potentiated exercise however the potentiating effects of the conditioning stimulus will dissipate with time (Comyns et al., 2006b; Gossen & Sale, 2000; Jensen & Ebben, 2003). From this information, performance enhancement from a conditioning stimulus should be expressed between 2-20 minutes depending on the conditioning stimulus (Gilbert & Lees, 2005). Any post-testing under a one minute duration may be insufficient for performance enhancements in PAP.

Positive and Non-Responders

With the many variables that can affect PAP, it is not unreasonable to suggest that PAP studies have tended to show both positive and non-responders to conditioning contractions. In a study using 13 trained men from varying disciplines who acted as their own controls, five modified drop jumps with one minute rest were used to potentiate three CMJ and three SJ with a rest period of 20 seconds (Hilfiker et al., 2007). Along with statistical significance in improvements in power of the CMJ it was also determined that there was a large variability in PAP between subjects. The authors concluding that four subjects improved in all four outcome parameters following modified drop jumps, three improved 3/4 times, three improved 2/4 times, three improved 1/4 times. Variability between subjects has also been found in other studies suggesting that PAP can vary significantly between subjects of a similar training status (Comyns et al., 2006b; O'leary et al., 1997; Smith & Fry, 2007; Till & Cooke, 2009; Yetter & Moir, 2008). While there could be a number of factors contributing to this phenomenon, it is clear that PAP may need to be evaluated on an individual basis for further understanding of intersubject variability.

Postactivation Potentiation and the Conditioning Stimulus

Multiple studies have used biomechanically similar conditioning activities in PAP (Gilbert & Lees, 2005; Hilfiker et al., 2007; Kilduff et al., 2007; Smilios et al., 2005; Yetter & Moir, 2008). While these studies have shown promising results in eliciting PAP, it is not certain whether the modality of the conditioning stimulus (concentric, eccentric, or isometric muscle actions) is a critical factor for optimal PAP potential. In a study by Baudry and Duchateau, 2004, nine subjects' dorsiflexor muscles were tested for PAP potential using a custom made flootplate that allowed for concentric and eccentric muscle actions. Using the subject's right foot, six

second muscle actions (either concentric, eccentric, or isometric) were used to potentiate subsequent electrical stimulation of the dorsiflexors. It was determined that potentiation of the three conditions were similar in both intensity and duration suggesting that PAP may not be related to the type of the conditioning stimulus. If RLC phosphorylation is the primary mechanism by which PAP occurs, then the conclusions of the aforementioned study would suggest that a high level of muscle action (regardless of the type of muscle action) for a duration of approximately six seconds would be sufficient for maximal release of calcium from the sarcoplasmic reticulum. The maximal release of calcium in turn would allow for high potential of RLC phosphorylation and could in turn result in the expression of PAP.

Summary

PAP is a unique phenomenon that involves increased twitch force amplitude following a potentiating exercise. While there are a number of mechanisms that have been proposed, the only mechanism that seems to contribute significantly to PAP is from an intramuscular source. Myosin RLC phosphorylation is an intramuscular mechanism that involves the interaction between calcium, calmodulin, and MLCK and in turn the phosphorylation of a structural protein on myosin heavy chain, RLC. Multiple studies have determined that RLC phosphorylation and PAP are highly associated with each other. Both PAP and RLC phosphorylation have very similar qualities and properties in terms of their activity duration and magnitude, making RLC phosphorylation a reasonable mechanism contributing to PAP. However, while RLC phosphorylation is a probable mechanism to explain PAP, more organized research is necessary to definitively confirm this process. At the same time, additional research is also needed to determine the optimal type of conditioning stimulus, duration, and variables that can be used and controlled to elicit PAP. In particular, the use of biomechanically similar conditioning stimuli for

eliciting PAP is highly suspect considering a recent study that found contradictory evidence. It does not appear that the type of conditioning stimulus for eliciting PAP need be similar in muscle action. Instead, PAP could be elicited by simply using similar musculature that is used in the potentiated exercise at near maximal intensity, however, this has yet to be explored. The application of the knowledge gained from the current review was used to develop an up to date protocol for eliciting PAP in an acute setting.

Chapter III

Methods and Procedures

Introduction

The goal of the study was to determine if 3 sets of a 6-second maximal isometric quarter squat exercise protocol was sufficient at potentiating force and power variables in a countermovement jump. Optimal duration for PAP occurrence between 1-15 minutes was also a variable that was measured. Five dependent variables were measured to analyze the effect of a conditioning stimulus on PAP, which included ERFD, MRFD, PRFD, RSI, and PP. One preliminary session was used for the subjects to become familiar with the protocol and also to become comfortable with countermovement jump testing on a force platform. The following sessions were used to test the effects of an isometric conditioning stimulus on CMJ characteristics including ERFD, MRFD, PRFD, RSI, and PP. Descriptions of the subject, research design, instrumentation, data collection and statistical procedure are all included in this chapter.

Description of Subjects

The subject sample consisted of 22 recreationally trained individuals who were actively involved in resistance training for at least one year prior to the start of the study. In addition, subjects were required to have at least six months experience and be actively involved in sports involving jumping or explosive type movements.

Design of the Study

The design of the study was a repeated measures design with all subjects being tested before and after a potentiating protocol. Each subject was also tested in both the control and experimental protocol.

Data Collection Procedures

This protocol was approved by the committee for Human Subjects Protection at Western Washington University. All subjects were required to read and sign a hold harmless agreement and informed consent form. Data was collected in the Biomechanics Laboratory at Western Washington University. One preliminary session took place prior to testing in order to get acquainted with the procedures and to practice countermovement jump (CMJ) testing on a force platform. The second and third session included either a control or experimental protocol that was randomly selected followed by CMJs on an Advanced Mechanical Technology Inc. (AMTI; Watertown, MA) force platform which was used to measure ground reaction force (GRF). The force plate was set at a sampling rate of 1200 Hz and recorded three seconds of data. The subjects were instructed to stand on the force plate so their weight could be measured and recorded. The subjects were then asked to cross their arms across their chests so that their hands were grabbing their opposite shoulders. Subjects maintained this position throughout the CMJ. When the technician said "GO", the subjects performed a countermovement jump up and tried to jump as high and as quickly as possible. The Technician activated the trigger so that there was one second of data preceding the CMJ.

The Custom Made Apparatus

The isometric conditioning stimulus was performed on a custom-made apparatus and the subjects were set up to press from the quarter squat position. The apparatus consisted of a

platform (to stand on) with two chains that extended from the edges of the platform to a bar that rested on the shoulders of the subjects. The chains of the apparatus were shortened or lengthened according to the subject's height via two carabiners.

Methods of the First Session

Upon entering the biomechanics laboratory, subjects were asked to sign an informed consent and hold harmless agreement. The subjects were then asked to fill out a questionnaire and take part in a familiarization phase. The questionnaire was used to record self-reported height (meters), body mass (kg), and activity level. The familiarization phase allowed the subjects to practice the standard warm-up protocol, three sets of the conditioning stimulus, and six CMJs with one minute rest in between. The warm-up consisted of five minutes of cycling at 300 kg*m/min, 10 lunges, 10 deep squats, and 10 light hops. The conditioning stimulus consisted of three sets of six second isometric quarter squat which was achieved by pushing against the apparatus in an attempt to extend the hip, knee and ankle maximally. This standard warm-up protocol was used in all training sessions. All sessions were separated by four days to ensure the subjects were completely rested before the next session. Subjects were also asked to refrain from any high intensity exercise for at least 48 hours prior to each following session.

Methods of the Second and Third Session

The experimental and control condition were randomly selected for each subject over the second and third day. The condition that was not drawn of the second day was performed on the third day.

The Control Condition

In the control condition, testing for CMJ performance was administered following the standardized warm-up. After completion of the warm-up, five minutes of active rest (walking)

took place followed by five minutes of passive rest and pre-test measurements were taken. Subjects were then asked to stand in the middle of the force platform and perform a CMJ as high as possible in the vertical direction. Three pre-test maximal CMJs took place with one minute rest in between. At the end of the last pre-test CMJ, subjects rested for 2 minutes and 48 seconds to match the time allotted to transition from the force platform during pre-testing to the custom made apparatus and also complete the experimental procedure. CMJ post-testing consisted of a maximal CMJ at one, five, ten, and fifteen minutes following the rest period. The CMJ post-testing protocol remained consistent in both conditions.

The Experimental Condition

In the third session, subjects were first asked to take part in the standardized warm-up. Following the warm-up, five minutes of active rest and five minutes of passive rest took place and pre-test measurements were taken on the force platform. Upon completing pretesting, subjects had 30 seconds to transition and get positioned correctly into the custom made apparatus. Subjects were then asked to perform three six second isometric quarter squat by pushing against the custom made apparatus in an attempt to extend the hip, knee and ankle maximally. Each conditioning stimulus was separated by one minute rest in between. At the end of the conditioning stimulus protocol, CMJ post-testing took place at one, five, ten, and fifteen minutes.

Instrumentation

Kinetic data was collected using an Advanced Mechanical Technology Inc. (AMTI; Watertown, MA) force platform, which was used to measure ground reaction force (GRF). The force plate was set at a sampling rate of 1200 Hz. The hardware was interfaced with AMTI

Netforce software for data collection, and was converted to text files via AMTI Bioanalysis software for further processing.

Data Analysis

A custom made Labview program (National Instruments, Austin, TX) was used to determine eccentric rate of force development (ERFD), mean rate of force development (MRFD), peak rate of force development (PRFD), reactive strength index (RSI), and peak power (PP), based on the impulse-momentum relationship from the vertical GRF measured from the force platform. Eccentric rate of force development was determined by finding the differences between vGRF when COM velocity equals zero from $vGRF_{min,}$ divided by the time duration. Mean rate of force development was determined by calculating the difference between the minimum and maximum vertical GRF (VGRF) divided by the time from minimum and maximum VGRF (McLellan, Lovell, & Gass, 2011). Peak rate of force development was determined by the maximum change in force over a 10-millisecond time intervals during the countermovement jump (Bompa & Haff, 2009). Reactive strength index was determined by jump height (meters) divided by time (seconds) to takeoff (Zatsiorsky & Kraemer, 2006). Peak power was determined by the maximum power (force x velocity) during the countermovement jump (McLellan et al., 2011).

Statistical Analysis

Two-way repeated measures analyses of variance (ANOVA) were used to examine the effects of time (pre-test, 1, 5, 10 and 15 minutes) and condition (control vs. treatment) on MRFD, PRFD, RSI, PP, and ERFD. Statistical significance was set to $p < .01$, due to the Bonferroni correction from five dependent variables. Effect size was calculated using η^2 and evaluated according to the scale published by Rhea (2004): $\eta^2 > 1.50$ was large, $\eta^2 = 0.80\text{-}1.50$

was moderate, η^2 = 0.35-0.80 was small, η^2 > 0.35 was trivial. Statistical power was estimated to be significant at w^2 > 0.80.

Chapter IV

Results and Discussion

Introduction

The current study aimed to determine if an isometric quarter squat was sufficient to elicit PAP in a CMJ, and time course of this effect. PAP was measured using ERFD, MRFD, PRFD, RSI, and PP during each CMJ performed. Two-way repeated measures ANOVAs were used to examine the effects of time (pre- vs. post-1 vs. post 5 vs. post-10 vs. post-15) and condition (control vs. treatment) on ERFD, MRFD, PRFD, RSI, and PP. Subjects were tested three times prior to the conditioning stimulus spaced one minute apart for both sessions. Subjects were also tested at one, five, ten, and fifteen minutes following the warm-up and treatment protocol. Statistical significance was set to $p < .01$, effect size was calculated using η^2 and power was estimated to be significant at $w^2 > .80$. A complete statistical analysis can be viewed in Appendix E.

Subject Characteristics

Twenty-two (10 men, 12 women) ranging from 19 to 26 (22.82 ± 1.99) years of age volunteered for the study. All subjects were recreationally trained individuals who were actively involved in resistance training for at least one year prior to the start of the study. All subjects were actively involved in sports involving jumping or explosive type movements at least one time per week. Means and standard deviations for the subject characteristics are provided in Table 1.

Table 1.
Subject Characteristics

	Mean	SD
Subject Age (Years)	22.82	1.99
Subject Height (cm)	173.28	10.6
Subject Body Mass (kg)	71.43	11.57

Results

Eccentric Rate of Force Development. Mauchly's test indicated the assumption of sphericity had been violated for the main effect of time ($p < .001$), and the condition * time interaction ($p = .003$). Degrees of freedom, in turn, were corrected using Greenhouse-Geisser estimates. There was no significant interaction effect of condition and time on ERFD (F[2.25, 42.67] = .75, $p = .493$, $\eta^2 = .04$). There were also no main effects of either condition (F[1, 19] = .57, $p = .46$, $\eta^2 = .03$), nor time (F[1.34, 25.47] = 1.76, $p = .198$, $\eta^2 = .09$).

Mean Rate of Force Development. Mauchly's test indicated the assumption of sphericity had been violated for the main effects of time ($p < .001$), and condition * time interaction ($p = .131$). Degrees of freedom, in turn, were corrected using Greenhouse-Geisser estimates. There was no significant interaction effect of condition and time on MRFD (F[2.83, 59.32] = 1.81, $p = .16$, $\eta^2 = .079$). There were also no main effects of either condition (F[1, 21] = 1.22, $p = .28$, $\eta^2 = .06$)., nor time (F[2.02, 42.34] = .675, $p = .516$, $\eta^2 = .03$) on MRFD.

Peak Rate of Force Development. Mauchly's test indicated the assumption of sphericity had been violated for the main effects of time ($p < .001$), and condition * time interaction ($p < .001$). Degrees of freedom, in turn, were corrected using Greenhouse-Geisser estimates. There was no significant interaction effect of condition and time on PRFD (F[1.98, 39.54] = .667, $p = .52$, $\eta^2 = .03$). There were also no main effects of either condition (F[1, 20] = .36, $p = .56$, $\eta^2 = .017$), nor time (F[1.96, 39.13] = .667, $p = .38$, $\eta^2 = .05$).

Reactive Strength Index. Mauchly's test indicated the assumption of sphericity had been violated for the main effects of time ($p < .001$), and condition by time ($p = .003$). Degrees of freedom, in turn, were corrected using Greenhouse-Geisser estimates. There was no significant interaction effect of condition and time on RSI (F[2.32, 41.83] = 3.69, $p = .028$, $\eta^2 =$

.17). There were also no main effects of either condition (F[1, 18] = .148, p = .71, η^2 = .01), nor time (F[2.24, 40.33] = 2.07, p = .13, η^2 = .10).

Peak Power. Mauchly's test indicated the assumption of sphericity had been violated for the main effects of time (p < .001), and condition * time (p < .001). Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates. There was no significant interaction effect of condition and time on PP (F[2.13, 42.62] = .38, p = .70, η^2 = .02). There were also no main effects of either condition (F[1, 20] = .007, p = .93, η^2 = .00), nor time (F[2.09, 41.71] = 3.63, p = .03, η^2 = .15).

Discussion

The purpose of the current study was to determine if an isometric quarter squat was sufficient to elicit PAP in a CMJ at one, five, ten, and fifteen minutes post-conditioning stimulus in recreationally-trained individuals. PAP was indicated if there was a significant change in ERFD, MRFD, PRFD, RSI, or PP during each CMJ performed. Evaluation of these kinetic variables following a conditioning stimulus may give us some valuable information as to how a CMJ is potentiated resulting in acute enhanced performance, as well as its time course. The results indicated that there were no significant interaction or main effects of condition and time on any of the dependent variables. The overall effect size in all variables was consistently small, suggesting that an effect did not exist. A following discussion will review all five dependent variables.

Eccentric Rate of Force Development. There was no significant interaction effect of condition and time on ERFD. This does not support the experimental hypothesis, suggesting that ERFD was not affected by an isometric quarter squat in recreationally trained athletes. This is the

first study to the author's knowledge that has analyzed specifically ERFD and its effect on PAP in a CMJ.

ERFD is a mechanical variable that measures the rate of force development produced to actively slow an individual's body COM to a velocity of zero in preparation for the propulsive phase of a CMJ (Laffaye, Wagner, & Tombleson, 2014). Eccentric rate of force development which is a critical component of the stretch shortening cycle has been suggested to play a significant role in CMJ performance (Laffaye, Wagner, & Tombleson, 2014; Laffaye & Wagner, 2013). High levels of ERFD have been associated with decreasing time to peak force for increasing RFD, which is suggested to be an important component of explosive activities (Laffaye & Wagner, 2013). In one study, ERFD was found to be highly associated with vertical jump performance in 178 skilled athletes, suggesting it may play a critical role in CMJ performance (Laffaye & Wagner, 2013). Therefore, measuring ERFD could give some valuable insight into whether the eccentric component of force production in a CMJ could be affected by an isometric quarter squat.

ERFD allows for a large recruitment of high threshold motor units by rapidly lengthening muscle tissue and therefore stimulating the stretch shortening cycle for higher muscle recruitment (Bobbert & Casiuus, 2005). It has been suggested that rapid muscle stretching in the eccentric phase stimulates muscle spindles and increases neural stimulation and activation of higher threshold motor units at the start of the concentric phase of a CMJ (Bobbert & Casius, 2005). During the CMJ, agonist muscles are rapidly stretched during the eccentric phase, stimulating the stretch shortening cycle which raises muscle stimulation and allows energy to be stored in the elastic component of the musculotendinous unit for use in the propulsive or concentric phase (Laffaye & Wagner, 2013). This stored energy enables muscles to build a

higher active contraction state by which more force can be applied to the ground at the bottom of the CMJ. If potentiation were present in the current study, it is likely that ERFD would be acutely enhanced by phosphorylated RLC in fast twitch skeletal muscle fibers, resulting in greater force output and velocity of cross bridge cycling (Baudry & Duchanteau, 2007b; Moore & Stull, 1984; O'Leary et al., 1997). More efficient fast twitch muscle fibers would allow greater force to be generated and therefore applied to the ground to very quickly slow and change direction of the center of mass of the body.

Mean Rate of Force Development. There was no significant interaction effect of condition and time on MRFD. There were also no main effects of either condition nor time. These findings are not in agreement with the experimental hypothesis. MRFD is the average increase in vertical GRF (VGRF) with respect to time between the minimum and maximum vertical GRF (VGRF) of a CMJ (McLellan, Lovell, & Gass, 2011). MRFD may be a useful variable to measure because it gives us a representation of what happens with force across a specific time interval of the CMJ. This variable was measured to determine if the overall force from the point the individual begins applying force to the ground to the maximal force is augmented by an isometric quarter squat. This variable takes into account both the force and time it took to reach peak force. MRFD in turn can be a useful variable to measure for the faster peak force is reached in the CMJ, the greater the possibility of increasing the overall force applied to the ground (Bobbert & Casius, 2005; Laffaye, Wagner, & Tombleson, 2014; Laffaye & Wagner, 2013).

To the author's knowledge, very few studies have analyzed PAP using MRFD. The results from these studies analyzing MRFD are mixed with both significant (Gilbert & Lees, 2005; Gullich & Schmidtbleicher, 1996) and non-significant (Esformes, Keenan, Moody, &

Bampouras, 2011) changes in performance. In one study, 34 athletes exerted maximal force onto the platform with the ball of the foot in order to measure kinetic variables across time (Gullich & Schmidtbleicher, 1996). MRFD was determined as the average rise in force over a 30 millisecond time period (Gullich & Schmidtbleicher, 1996). It was determined that a few MVCs were sufficient to cause increases in MRFD, with the highest force performances ranging between 4.5 and 12.5 minutes post-potentiation (Gullich & Schmidtbleicher, 1996).

Another study calculated RFD as the first derivate of the force signal (Gilbert & Lees, 2005). Isometric rate of force development (iRFD) of the quadriceps (90 degree knee angle) was calculated by determining the change in force per unit of time over a period of 50 milliseconds using a rolling mean method (Gilbert & Lees, 2005). Using 15 male athletes, five 1RM back squats with five minutes rest in between were used as the conditioning stimulus (Gilbert & Lees, 2005). It was determined that five 1 RM back squats were sufficient to cause significant increases in iRFD at 15 minutes and 20 minutes with an overall peak increase of 11.8% at 20 minutes post 1 RM (Gilbert & Lees, 2005).

MRFD in the current study was measured with a CMJ, which requires a considerable amount of skill and coordination across multiple body segments (Hara et al., 2005; Feltner, Fraschetti, & Crisp, 1999; Shetty, & Etnyre, 1989). At the same time, the body was moving during the measurement of MRFD in the current study whereas the aforementioned studies measured PAP from a single joint in a fixed position. All of these variations may have affected the results the current study however due to the variation in testing methods across multiple studies, likely contributors to the current studies results is limited.

Peak Rate of Force Development. The current results indicated no significant interaction effect of condition and time on PRFD, nor was there a main effect of the condition or

time. These results are not in agreement with the experimental hypothesis, suggesting that an isometric quarter squat does not augment PRFD in a CMJ. PRFD represents the greatest increase in vertical GRF (VGRF) with respect to time, over a 10 millisecond window between the beginning and end of the vertical CMJ (McLellan, Lovell, & Gass, 2011). PRFD has been shown to be significantly correlated with vertical jump displacement (McLellan et al., 2011).

The results of the current study are not in agreement with previous research investigating PRFD and PAP (Arabatzi et al., 2014; Comyns et al., 2006a). One study measured the PAP effect on squat jump performance measured via PRFD in both male and female subjects across preadolescent (10-12 years), adolescents (14-15 years), and adults (20-25 years) (Arabatzi et al., 2014). Using 58 moderately trained male and female subjects with a conditioning protocol consisting of three sets of three second maximal isometric squats, the aforementioned study tested jump performance at 20 seconds and four minutes post conditioning stimulus. It was determined that three sets of three MVCs were sufficient to cause increases in PRFD in a squat jump for both adult male and female subjects minutes post-potentiation (Arabatzi et al., 2014).

Differences in the results of the current study may have been due to the subjects performing a CMJ versus a squat jump in the aforementioned study. The results may have also been due to the position in which subjects performed the isometric quarter squat. The current study positioned subjects in a quarter squat while Arabatzi et al. (2014) positioned subjects in a half squat with the knee joint angle set at 90 degrees. One study in particular found that different squat depths can induce PAP to varying levels (Esformes & Bampouras, 2013). Using 27 semiprofessional male rugby players, CMJ performance was examined following either three 3RM parallel back (PS) squats or quarter squats (QS). While both protocols found significant increases in CMJ performance five minutes post conditioning stimulus, the PS was more

beneficial for subsequent CMJ performance than the QS (Esformes & Bampouras, 2013). It was suggested that this was likely due to increases in gluteus maximum activation from the deeper depth of the PS (Esformes & Bampouras, 2013). Muscle activity of specific muscle groups was not measured in the current study, however research suggests that an isometric quarter squat may not have not been optimal for maximal recruitment of prime movers of the CMJ (Esformes & Bampouras, 2013).

Reactive Strength Index. There was no significant interaction effect of condition and time on RSI, nor was there a main effect of the condition or time. These findings are not in agreement with the experimental hypothesis, suggesting that RSI is not affected by an isometric quarter squat in recreationally trained athletes. RSI provides a representation of explosive strength and is calculated as jump height (meters) divided by the time to takeoff (seconds) (Zatsiorski & Kraemer, 2006; Young, 1995). The effectiveness of the stretch shortening cycle has been described using RSI (Young, 1995).

A few studies have analyzed RSI and its relation to PAP. In one study, ten male subjects performed a series of maximum effort rebound throws (RBT) using a custom made upper limb sledge apparatus until a 90% fatigue criterion was achieved (Harrison, 2011). Following the fatigue protocol, subjects were asked to perform three RBT at 15, 45, 120, and 300 seconds. It was determined that mean throwing performance was increased approximately 8% 300 seconds post-fatigue protocol, and a 7% increase in RSI on average post-fatigue intervention (Harrison, 2011). This protocol differed from the current study for it involved upper body dynamic explosive power and a fatiguing protocol. Another study found similar results using a 90% fatiguing protocol on lower body extremity performance which was similar to the aforementioned study finding trends toward decreases in ground contact time and increases in flight time while finding significant

increases in leg-spring stiffness at 300 seconds post-fatiguing protocol (Comyns et al., 2006a). The current study intended to limit fatigue however measurements of fatigue were not directly measured. Therefore, a specific level of muscle activation with minimal fatigue may be necessary to see significant enhancement in RSI.

Peak Power. There was no significant interaction effect of condition and time on PP. There were also no main effects of neither condition nor time. These results refute the experimental hypothesis, suggesting that PP is not affected by an isometric quarter squat in recreationally trained athletes. PP is the measure of the maximal product of force and velocity generated during the CMJ. This is a variable that provides insight into the explosive capacity of an individual, taking into account both force and velocity. PP is a kinetic variable that is significantly correlated with vertical jump displacement (McLellan et al., 2011). PP is a promising kinetic variable for measuring PAP because the mechanisms that have been proposed to drive PAP (RLC phosphorylation) have been shown to increase in the maximal velocity of muscle shortening (Baudry & Duchanteau, 2007b; Moore & Stull, 1984; O'Leary et al., 1997) and show an upward shift in the load-velocity curve (Baudry & Duchanteau, 2007b).

While the current study failed to enhance performance following a maximal isometric conditioning stimulus, other researchers have found significant enhancements in power using lower body (Esformes et al., 2011; Kilduff et al., 2007) and upper body conditioning stimuli (Kilduff et al., 2007) in both elite (Hilfiker et al., 2007; Kilduff et al., 2007) and recreationally trained individuals (Chiu et al., 2003). A few studies have found no differences or decreases in PP (Brandenburg, 2005; Tsolakis et al., 2011). In studies that found significant changes in PP performance, subjects were highly trained individuals. However, one study found that elite fencers (Tsolakis et al., 2011) did not see improvements in PP following a conditioning stimulus

of three sets of five maximal effort tuck jumps or three sets of three second isometric leg presses. However, inclusion criteria in the aforementioned study required that subjects have at least one year of experience with resistance training but no objective measures of absolute strength were evaluated (Tsolakis et al., 2011). Therefore, the subjects in the study may not have had the ideal characteristics to express PAP.

One study investigating upper body concentric-only throws using recreationally trained kinesiology students performing five repetition bench press throws at five repetitions of 50, 75, and 100% of 5 RM conditioning stimulus load is in agreement with the current study, suggesting that training status may have been a contributor to the results of the study (Brandenburg, 2005). The effect of training level in PP may be an important feature to express potentiation. Highly trained individuals have enhanced energy system development, improved fatigue resistance, and a more rapid recovery from fatigue (Brooks, Fahey, & Baldwin, 2005). These physiological characteristics in theory would allow for greater opportunity to enhanced PP from a conditioning stimulus before full de-phosphorylation of the MLCK takes place. However, the type of conditioning stimulus may also play a vital role in whether PAP is acutely maximized.

Conditioning Stimulus. In the current study, we attempted to induce potentiation by performing a six second isometric maximal-effort quarter squat. Other studies have sufficiently induced potentiation using isometric muscle actions (Arabatzi et al., 2014; Baudry & Duchateau, 2007a; Baudry & Duchateau, 2007b; French et al., 2003; Gossen & Sale, 2000; Hamada et al., 2000; Rixon, Lamoth, & Bemben, 2007) in both athletes and recreationally trained individuals. However, other studies have found that multiple conditioning stimuli including dynamic (Comyns, Harrison, & Hennessy, 2006b; Kilduff et al., 2007) and plyometric (Hilficker et al., 2007; Till and Cooke, 2009) contractions at maximal (Arabatzi et al., 2014; Baudry &

Duchateau, 2007a; Baudry & Duchateau, 2007b; French et al., 2003; Gossen & Sale, 2000; Hamada et al., 2000; Harrison, 2011) or sub-maximal levels (Comyns, Harrison, & Hennessy, 2006b; Gilbert & Lees, 2005; Hilfiker et al., 2007; Klein et al., 2001; Mangus et al., 2006; Smilios et al., 2005; Yetter & Moir, 2008) were sufficient to potentiate exercises in both the upper and lower body extremities using both athletic and recreationally trained athletes. The successful use of multiple conditioning stimuli suggests that PAP can be elicited under a wide range of conditions. The root cause of is difficult to determine for there are large variations in testing protocols, however improved performance after a conditioning stimulus may depend largely on the interplay between potentiation and fatigue (Rassier et al., 2000). The goal in optimizing PAP is to maximize potentiation and minimize fatigue or measure performance right after fatigue has subsided. The current study may not have involved an optimum stimulus to induce potentiation in recreationally trained subjects because the isometric squat depth may have not been sufficient to induce potentiation (Esformes & Bampouras, 2013). In addition, the current study did not include any measures to determine if a maximal effort was actually performed during the isometric quarter squat, although maximal effort during testing was encouraged for each subject.

Level of Conditioning. Subjects in the current study were required to be resistance trained for one year prior to the study and were also required to be actively participating in explosive movements. However, the intensity and quality of the training was not specifically measured. Therefore, the level of training, strength, and therefore capacity to potentiate between subjects could have varied significantly. The link between subjects' physiological and training characteristics on PAP enhancement has been examined by one study which analyzed the effect of training status on PAP determining that PAP was a feasible method for increasing

performance in athletes (n = 7) but not recreationally trained (n =17) individuals (age = 23.42 +/- 2.89) (Chiu et al., 2003). Enhanced potentiation in the athletic population is consistent in a number of studies (French et al., 2003; Hilfiker et al., 2007; Kilduff et al., 2007; Yetter & Moir, 2008), however potentiation has also been observed in the recreationally trained population (Gilbert & Lees, 2005; Hamada et al., 2000), and untrained population (Baudry & Duchateau, 2007a; Baudry & Duchateau, 2007b; O'leary et al., 1997). A few studies have failed to observe PAP in athletic (Till & Cooke, 2009) or recreationally trained subjects (Brandanburg, 2005, Magnus et al., 2006; Scott & Docherty, 2004; Smith & Fry, 2007). The expression of PAP may be due in part to a trained individual's enhanced rate of recovery and reduced overall fatigue following the conditioning stimulus (Rassier & MacIntosh, 2000; Tillin & Bishop, 2009). PAP in highly trained and elite athletes may also be due to their overall high level of relative strength compared to non-athletes, which seems to be an important characteristic of PAP potential (Hamada et al., 2000; Hilfiker et al., 2007; Yetter & Moir, 2008). This is likely because type II muscle fibers are better able to potentiate compared to type I fibers due to the greater level of phosphorylation taking place in RLC fast twitch skeletal muscle (Hamada et al., 2000; Moore & Stull, 1984). It is important to note that the majority of PAP studies vary greatly in procedure, variables analyzed, and conditioning stimulus performed. However, part of the inconsistencies in PAP research may be in part due to the testing criteria of subject relative strength profiles and experience to explosive type activities.

In the current study, we performed no objective measurement of the subjects' relative or absolute strength, which could have provided valuable information as to why PAP was not expressed in the current study. Other studies have objectively measured individuals' absolute and relative strength, determining that individuals with overall greater strength were better able to

potentiate (Chiu et al., 2003; Gilbert & Lees, 2005; Yetter & Moir, 2008). However, some studies have used minimum strength requirements (1 RM of at least the subject's body mass) in kinesiology students for inclusion into PAP studies with no significant changes in performance (Brandenburg, 2005). Other studies have used no minimum strength requirements and have reported enhancement in performance (Comyns, Harrison, & Hennessy, 2006b; Esformes et al., 2011; Hilfiker et al., 2007; Kilduff et al., 2007). It is important to note that the subjects included in these studies were elite athletes who were highly trained in plyometric type activities (Comyns, Harrison, & Hennessy, 2006b; Esformes et al., 2011; Hilfiker et al., 2007; Kilduff et al., 2007). One study using elite fencers did not find any significant PAP; however, inclusion criteria for absolute or relative strength were not included (Tsolakis et al., 2011). One study that did not use objective measures of strength as inclusion criteria or high level athletes but found significant enhancement in performance (Arabatzi et al., 2014). However, these subjects had at least 3-6 years of experience in explosive power events (Arabatzi et al., 2014).

Collectively, this information suggests that physically stronger individuals may have a higher PAP potential compared to weaker individuals. These individuals are also much more likely to show enhancement in performance following a conditioning stimulus. A minimum criterion for the relative strength profiles of the subjects included in the current study may have been useful in identifying individuals who are more likely to potentiate. Further, individuals who have extensive experience in explosive type activities tend to show positive enhancements in performance. More information will be needed in order to support these claims due to mixed results from current literature.

Summary

The purpose of the current study was to determine if an isometric quarter squat was sufficient to elicit PAP in a CMJ at one, five, ten, and fifteen minutes post-conditioning stimulus. There was no significant change in ERFD, MRFD, PRFD, RSI, and PP during each CMJ performed. The results indicated that there was no significant interaction in any of the dependent variables.

Some variables that may have contributed to the results of the current study include variation in testing parameters, the subjects' overall capacity to potentiate, body positioning of the conditioning stimulus, and level of conditioning of the subjects. However, further analysis would need to be necessary to order to test or control for these variables.

Chapter V

Summary, Conclusion, and Recommendations

Summary

Postactivation potentiation is a property of skeletal muscle that enhances muscular performance following a high intensity conditioning stimulus (Gilbert & Lees, 2005). There are multiple mechanisms that have been proposed for PAP, but the likely mechanism that seems to contribute significantly to PAP are from an intramuscular source. This physiological process likely involves an intramuscular mechanism that ultimately results in altered contractile properties of muscle for a finite time period (Moore and Stull, 1984; Palmer & Moore, 1989; Rassier & MacIntosh, 2000; Smith & Fry, 2007; Stull et al., 2011; Szczesna et al, 2002). Myosin RLC phosphorylation, the proposed mechanism to PAP, involves the interaction of calcium, calmodulin, and MLCK to phosphorylate RLC. RLC is a structural protein on myosin heavy chain that has been suggested to allow movement of the myosin head out of the resting state in muscle fibers and likely plays a critical role in crossbridge cycling (Stull et al., 2011).

PAP has been implemented in training programs in the form of complex training (Ebben & Watts, 1998). However, there are often major differences between studies in the procedures used to elicit PAP (Rassier & MacIntosh, 2000; Robbins, 2005; Stull et al., 2011). There is also a lack of consistency in standardizing and measuring variables that affect PAP (Rassier & MacIntosh, 2000; Robbins, 2005; Stull et al., 2011). The objective in PAP studies has focused on maximizing force production in athletes and competitors, however other studies have used recreationally trained or individuals who meet a minimum relative strength profiles (Chiu et al., 2003; Gilbert & Lees, 2005; Yetter & Moir, 2008).

Guidelines for PAP parameters have been explored in animal (Close & Hoh, 1968; Moore and Stull, 1984; Palmer & Moore, 1989; Szczesna et al., 2002) and human models (Baudry & Duchateau, 2007a; Baudry & Duchateau, 2007b; Brandanburg, 2005; Comyns, Harrison, Hennessy & Jensen, 2007; French et al., 2003; Garner et al., 1989; Garner et al., 1989; Gilbert & Lees, 2005; Gossen & Sale, 2000; Hamanda et al., 2000; Kilduff et al., 2007), both in vivo (Baudry & Duchateau, 2007b; Moore and Stull, 1984; O'leary et al., 1997; Palmer & Moore, 1989; Zhi et al., 2005) and in vitro (Close & Hoh, 1968; Szczesna et al, 2002) under multiple experimental designs and subject populations including dynamic (Comyns, Harrison, & Hennessy, 2006b; Comyns et al., 2007; Kilduff et al., 2007), isometric (French et al., 2003; Gosen and Sale, 2000; Hamada et al., 2000) and plyometric (Hilficker et al., 2007; Till and Cooke, 2009) contractions at maximal (Arabatzi et al., 2014; Baudry & Duchateau, 2007a; Baudry & Duchateau, 2007b; French et al., 2003; Gossen & Sale, 2000; Hamada et al., 2000; Harrison, 2011) or sub-maximal levels (Comyns, Harrison, & Hennessy, 2006b; Comyns et al., 2007; Gilbert & Lees, 2005; Hilfiker et al., 2007; Klein et al., 2001; Mangus et al., 2006; Smilios et al., 2005; Yetter & Moir, 2008). These studies have also evaluated potentiating exercises in both the upper and lower body extremities.

The current study was designed to determine whether an isometric quarter squat was sufficient to elicit PAP in a CMJ in recreationally trained individuals. PAP was measured using ERFD, MRFD, PRFD, RSI, and PP during each CMJ performed. The results indicated that there was no significant PAP effect in any of the dependent variables. Some critical factors that may have contributed to the results include the subjects' overall ability to potentiate, body positioning during conditioning stimulus, and level of conditioning of subjects. Further analysis would need to be necessary to order to test or control for these factors.

Conclusions

The current study failed to reject the null hypothesis demonstrating that there was no significant or meaningful change in ERFD, MRFD, PRFD, RSI, or PP during each CMJ performed. The overall power was small for all variables suggesting that the ability of the current study to observe an effect that might have existed was very unlikely. Effect size was also small in all variables suggesting that the change pre to post-testing was not meaningful. Some critical factors that may have contributed to the results include an individual's ability to potentiate, body positioning during conditioning stimulus, and level of conditioning of subjects.

Recommendations

Future Research. Having an objective measure of each individual's peak performance capacity along with a measure during the conditioning stimulus may be useful in determining if a maximal or near maximal effort was actually performed in the future. Objective measures like changes in RFD or PP during the conditioning stimulus may also be useful for it could indicate if fatigue was present which could give valuable insight into whether the effects of PAP was optimized during testing.

The optimal position to generate force from an isometric quarter squat may need to be investigated further for some research has suggested that a quarter squat versus a half squat show differences in PAP. Future investigations should be performed to determine which positions elicit the greatest force during testing so that maximal muscle recruitment in the tested movement pattern can be obtained.

A minimum criteria for the relative strength profiles of the subjects may be useful in selecting subjects who are more likely to potentiate. In addition, individuals who have extensive

experience in explosive type activities tend to show positive enhancements in performance, and therefore, this may be a useful criteria for future studies.

The level of training for the subject population may be an important feature to express potentiation. This is likely due to the enhanced energy system development, improved fatigue resistance, and rapid recover from fatigue (Brooks, Fahey, & Baldwin, 2005). The use of highly trained or elite athletes may also be useful for the relatively higher level of relative strength compared to non-athletes (Hamada et al., 2000; Hilfiker et al., 2007; Yetter & Moir, 2008).

Practical Applications. A six-second isometric quarter squat may not be sufficient to elicit PAP in recreationally trained males and females. Kinetic variables including ERFD, MRFD, PRFD, RSI, and PP may be useful tool in determining how PAP enhances a CMJ. Further research is necessary to determine the best strategies for eliciting and measuring PAP in a CMJ. Along with p-values, statistical power and effect size are necessary to determine both the probability and magnitude of an effect when measuring multiple kinetic variables.

References

Arabatzi, F., Patikas, D., Zafeiridis, A., Giavroudis, K., Kannas, T., Gourgoulis, V., & Kotzamanidis, C. M. (2014). The post-activation potentiation effect on squat jump performance: Age and sex effect. *Pediatric Exercise Science. 26*(2), 187-194. doi:10:1123/pes.2013-0052

Baechle, T. R., & Earle, R. W. (2008). Essentials of Strength Training and Conditioning (3rd ed.). Champaign, IL: Human Kinetics

Batista, M. A., Roschel, H., Barroso, R., Ugrinowitsch, C., & Tricoli, V. (2011). Influence of strength training background on postactivation potentiation response. *Journal of Strength and Conditioning Research, 25*(9), 2496-2502.

Baudry, S., & Duchateau, J. (2004). Postactivation potentiation in human muscle is not related to the type of maximal conditioning contraction. *Muscle and Nerve, 30*, 328-336. doi:10.1002/mus.20101

Baudry, S., & Duchateau, J. (2007a). Postactivation potentiation in a human muscle: Effect on the load-velocity relation of tetanic and voluntary shortening contractions. *Journal of Applied Physiology, 103*(4), 1318-1325.

Baudry, S., & Duchateau, J. (2007b). Postactivation potentiation in a human muscle: Effect on the rate of torque development of tetanic and voluntary isometric contractions. *Journal of Applied Physiology, 102*(4), 1394-1401.

Bobbert, M. F., & Casius, L. J. R. (2005). Is the Effect of a countermovement on jump height due to active state development? *Medicine and Science in Sports and Exercise, 37*(3), 440-446. doi:10.1249/01.MSS.0000155389.34538.97

Bompa, T. O., & Haff, G. G. (2009). *Periodization: Theory and Methodology of Training* (5th ed.). Champaign, IL: Human Kinetics.

Brandenburg, J. P. (2005). The acute effects of prior dynamic resistance exercise using different loads on subsequent upper-body explosive performance in resistance-trained men. *Journal of Strength and Conditioning Research, 19*(2), 427-432.

Brooks, G. A., Fahey, T. D., & Baldwin, K. M. (2005). *Exercise Physiology: Human Bioenergenics and Its Applications* (4th ed.). New York: McGraw Hill.

Brown, G. L., & von Euler, U. S. (1938). The after effects of a tetanus on mammalian muscle. *Journal of Physiology*, *93*, 39-60.

Buchthal, F., & Schmalbruch, H. (1970). Contraction times of twitches evoked by H-reflexes. *Acta Physiologica Scandinavica,* 80(3), 378-82.

Capaday, C. (1997). Neurophysiological methods for studies of the motor system in freely moving human subjects. *Journal of Neuroscience Methods,* 74(2), 201-218.

Chiu, L. Z. F. , Fry, A. C., Weiss, L. W., Schilling, B. K., Brown, L. E., & Smith, S. L. (2003). Postactivation potentiation response in athletic and recreationally trained individuals. *Journal of Strength and Conditioning Research, 17*(4), 671-677.

Close, R., & Hoh, J. F. (1968). The after-effects of repetitive stimulation on the isometric twitch contraction of rat fast skeletal muscle. *The Journal of Physiology,* 197(2), 461-477.

Comyns, T. M., Harrison, A. J., & Hennessy, L. K. (2006a). The effect of a maximum stretch-shortening cycle fatigue workout on fast stretch-shortening cycle performance. In *23rd International Symposium on Biomechanics in Sport* (pp. 46–49). University Salzburg: Austria.

Comyns, T. M., Harrison, A. J., & Hennessy, L. K. (2006b). The optimal complex training rest interval for athletes from anaerobic sports. *Journal of Strength and Conditioning Research, 20,* 471–476.

Comyns, T. M., Harrison, A. J., Hennessy, L., & Jensen, R. L. (2007). Identifying the optimal resistive load for complex training in male rugby players. *Sports Biomechanics, 6,* 59–70. doi:10.1080/14763140601058540

Ebben, W. P., & Watts, P. B. (1998). A review of combined weight training and plyometric training modes: Complex training. *Strength and Conditioning,* 20(5), 18-27.

Esformes, J. L., & Bampouras, T. M. (2013). Effect of back squat depth on lower-body postactivation potentiation. *Journal of Strength and Conditioning Research, 27*(11), 2997-3000.

Esformes, J. I., Keenan, M., Moody, J., & Bampouras, T. M. (2011). Effect of different types of conditioning contraction on upper body postactivation potentiation. *Journal of Strength and Conditioning Research, 25*(1), 143-148.

Feltner, M. E., Fraschetti, D. J., & Crisp, R. J. (1999). Upper extremity augmentation of lower extremity kinetics during countermovement vertical jumps. *Journal of Sports Sciences, 17*, 449-466.

Field, A. (2013). *Discovering statistics using IBM SPSS statistics* (4th ed.). Thousand Oaks, CA: Sage.

French, D. N., Kraemer, W. J., & Cooke, C. B. (2003). Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *Journal of Strength and Conditioning Research,* 17(4), 678-685.

Folland, J. P., Wakamatsu, T., & Fimland, M. S. (2008). The influence of maximal isometric activity on twitch and H-reflex potentiation, and quadriceps femoris performance. *European Journal of Applied Physiology, 104*, 739-748. doi: 10.1007/s00421-008-0823-6

Gallagher, P. J., Herring, B. P., & Stull, J. T. (1997). Myosin light chain kinases. *Journal of Muscle Research and Cell Motility,* 18(1), 1-16.

Garner, S. H., Hicks, A. L., & McComas, A. J. (1989). Prolongation of twitch potentiating mechanism throughout muscle fatigue and recovery. *Experimental Neurology,* 103(3), 277-281.

Gilbert, G., & Lees, A. (2005). Changes in the force development characteristics of muscle following repeated maximum force and power exercise. *Ergonomics, 48,* 1576-1584.

Gordon, A. M., Homsher, E., & Regnier, M. (2000). Regulation of contraction in striated muscle. *Physiological Reviews, 80*(2), 853-924.

Gossen, E. R., & Sale, D. G. (2000). Effect of postactivation potentiation on dynamic knee extension performance. *European Journal of Applied Physiology, 83*(6), 524-30.

Gullich, A., & Schmidtbleicher, D. (1996). MVC-induced short-term potentiation of explosive force. *New Studies in Athletics, 11*(4), 67-84.

Hamada, T., Sale, D. G., MacDougall, J. D., & Tarnopolsky, M. A. (2000). Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *Journal of Applied Physiology, 88*(6), 2131-2137.

Hara, M., Shibayama, A., Takeshita, D., & Fukashiro, S. (2006). The effect of arm swing on lower extremities in vertical jumping. *Journal of Biomechanics, 39*, 2503-2511. doi:10.1016/j.jbiomech.2005.07.030

Hilfiker, R., Hübner, K., Lorenz, T., & Marti, B. (2007). Effects of drop jumps added to the warm-up of elite sport athletes with a high capacity for explosive force development. *Journal of Strength and Conditioning Research, 21*(2), 550-555.

Kilduff, L. P., Bevan, H. R., Kingsley, M. I., Owen, N. J., Bennett, M. A., Bunce, P. J., Hore, A. M., ... Cunningham, D. J. (2007). Postactivation potentiation in professional rugby players: Optimal recovery. *Journal of Strength and Conditioning Research, 21*(4), 1134-1138.

Klein, C. S., Ivanova, T. D., Rice, C. L., & Garland, S. J. (2001). Motor unit discharge rate following twitch potentiation in human triceps brachii muscle. *Neuroscience Letters, 316*(3), 153-156.

Laffaye, G., & Wagner, P. (2013). Eccentric rate of force development determines jumping performance. *Computer Methods in Biomechanics and Biomedical Engineering, 16*(S1), 82-83.

Laffaye, G., Wagner, P. P., & Tombleson, T. I. (2014). Countermovement jump height: Gender and sport-specific differences in the force-time variables. *Journal of Strength and Conditioning Research. 28*(4), 1096-1105. doi:10.1519/jsc.0bo13e3182a1db03

Lowey, S., & Trybus, K. M. (2010). Common structural motifs for the regulation of divergent class II myosins. *Journal of Biological Chemistry*, 285(22), 16403-16407.

Luca, C. J. D., Foley, P. J., & Erin, Z. (1996). Motor unit control properties in constant-force isometric contractions. *Journal of Neurophysiology*, 76(3), 1503-1516.

Mangus, B. C., Takahashi, M., Mercer, J. A., Holcomb, W. R., McWhorter, J. W., & Sanchez, R. (2006). Investigation of vertical jump performance after completing heavy squat exercises. *Journal of Strength and Conditioning Research, 20*(3), 597-600.

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011). The role of rate of force development on vertical jump performance. *Journal of Strength and Conditioning Research, 25*(2), 379-385.

Moore, R. L., & Stull, J. T. (1984). Myosin light chain phosphorylation in fast and slow skeletal muscles in situ. *The American Journal of Physiology*, 247(5), 462-471.

O'Leary, D. D., Hope, K., & Sale, D. G. (1997). Posttetanic potentiation of human dorsiflexors. *Journal of Applied Physiology*, 83(6), 2131-2138.

Padre, R. C., & Stull, J. T. (2000a). Conformational requirements for Ca(2+)/calmodulin binding and activation of myosin light chain kinase. *FEBS Letters, 472*(1), 148-152.

Padre, R. C., & Stull, J. T. (2000b). Functional assembly of fragments from bisected smooth muscle myosin light chain kinase. *The Journal of Biological Chemistry*, 275(35), 26665-26673.

Palmer, B. M., & Moore, R. L. (1989). Myosin light chain phosphorylation and tension potentiation in mouse skeletal muscle. *The American Journal of Physiology*, 257(5), 1012-1019.

Palmieri, R. M., Ingersoll, C. D., Hoffman, M. A. (2004). The hoffman reflex: Methodologic considerations and applications for use in sports medicine and athletic training research. *Journal of Athletic Training, 39*(3), 268-277.

Rassier, D. E., & Macintosh, B. R. (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research, 33*(5), 499-508.

Rhea, M. R. (2004). Determining the magnitude of treatment effects in strength training research through the use of the effect size. *Journal of Strength and Conditioning, 18*(4), 918-920.

Rixon, K. P., Lamont, H. S., & Bemben, M. G. (2007). Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance. *Journal of Strength and Conditioning, 21*(2), 500-505.

Robbins, D. W. (2005). Postactivation potentiation and its practical applicability: A brief review. *Journal of Strength and Conditioning Research,* 19(2), 453-458.

Robertson, D. G. E., Caldwell, G. E., Hamill, J., Kamen, G., & Whittlesey, S. N. (2004). *Research Methods in Biomechanics*. Champaign, IL: Human Kinetics.

Scott, S. L., & Docherty, D. (2004). Acute effects of heavy preloading on vertical and horizontal jump performance. *Journal of Strength and Conditioning Research,* 18(2), 201-205.

Shetty, A. B., & Etnyre, B. R. (1989). Contribution of arm movement to the force components of a maximum vertical jump. *The Journal of Orthopaedic and Sports Physical Therapy, 11*(5), 198-201.

Smilios, I., Pilianidis, T., Sotiropoulos, K., Antonakis, M., & Tokmakidis, S. P. (2005). Short-term effects of selected exercise and load in contrast training on vertical jump performance. *Journal of Strength and Conditioning Research,* 19(1), 135-139.

Smith, J. C., & Fry, A. C. (2007). Effects of a ten-second maximum voluntary contraction on regulatory myosin light-chain phosphorylation and dynamic performance measures. *Journal of Strength and Conditioning,* 21(1), 73-76.

Stull, J. T., Kamm, K. E., & Vandenboom, R. (2011). Myosin light chain kinase and the role of myosin light chain phosphorylation in skeletal muscle. *Archives of Biochemistry and Biophysics, 510*(2), 120-128.

Szczesna, D., Zhao, J., Jones, M., Zhi, G., Stull, J., & Potter, J. D. (2002). Phosphorylation of the regulatory light chains of myosin affects Ca2+ sensitivity of skeletal muscle contraction. *Journal of Applied Physiology*, 92(4), 1661-1670.

Till, K. A., & Cooke, C. (2009). The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *Journal of Strength and Conditioning Research, 23*(7), 1960-1967.

Tillin, N., & Bishop, D. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Medicine,* 39(2), 147-166.

Tsolakis, C., Bogdanis, G. C., Nikolaou, A., & Zacharogiannis, E. (2011). Influence of type of muscle contraction and gender on postactivation potentiation of upper and lower limb explosive performance in elite fencers. *Journal of Sports Science and Medicine, 10*, 577-583.

Wilson, J. M., Kunkan, N. M., Marin, P. J., Brown, L. E., Loenneke, J. P., Winson, S. M. C., Jo, E., … Ugrinowitsch, C. (2013). Meta-analysis of postactivation potentiation and power: Effects of conditioning activity, volume, gender, rest periods, and training status. *Journal of Strength and Conditioning Research, 27*(3), 854-859.

Yetter, M., & Moir, G. L. (2008). The acute effects of heavy back and front squats on speed during forty-meter sprint trials. *Journal of Strength and Conditioning Research, 22*(1), 159-165.

Young, W. (1995). Laboratory strength assessment of athletes. *New Studies in Athletics*, *10*, 88-96.

Zatsiorsky, V. M., & Kraemer, W. J. (2006). *Science and Practice of Strength Training* (2nd ed.) Champaign, IL: Human Kinetics.

Zehr, E. P. (2002). Considerations for use of the Hoffmann reflex in exercise studies. *European Journal of Applied Physiology,* 86(6), 455-468

Zhi, G., Ryder, J. W., Huang, J., Ding, P., Chen, Y., Zhao, Y., Kamm, K. E., ... Stull, J. T. (2005). Myosin light chain kinase and myosin phosphorylation effect frequency-dependent potentiation of skeletal muscle contraction. *Proceedings of the National Academy of Sciences of the United States of America*, 102(48), 17519-17524.

Appendix A

Human Subjects Review Form and Responses

1. What is your research question or the specific hypothesis?

Specific Aim: The current study aimed to determine if an isometric quarter squat that activates similar musculature but is not biomechanically similar to a countermovement jump (CMJ) was sufficient to elicit postactivation potentiation (PAP) in a CMJ. Postactivation potentiation is a phenomenon involving enhanced contractile force and power properties of muscle following a high intensity muscular contraction. Indicators of PAP included mean rate of force development (MRFD), peak rate of force development (PRFD), reactive strength index (RSI), peak power (PP) and eccentric rate of force development (ERFD).

2. What are the potential benefits of the proposed research to the field?

There is a large body of research that has been done on the variables that affect the extent to which a high-force conditioning stimulus is able to potentiate a subsequent high-power movement. This study further investigates the type of conditioning stimulus that can be used to potentiate a CMJ. In addition, it will determine if potentiation can take place from very simple maximal isometric muscle action (pushing against a custom made apparatus) instead of an exercise that mimics the activity being potentiated (CMJ). The current study aims to determine if eliciting PAP is a much simpler task than previously suggested. In this case, PAP would require little to no equipment and this procedure could be used by a wider range of athletes in a variety of settings.

3. What are the potential benefits, if any, of the proposed research to the subjects?

Individual subjects of this study will gain no direct benefits.

4. Answer a), then answer either b) or c0 as appropriate.

a. Describe how you will identify the subject population, and how you will contact key individuals who will allow you access to that subject population or database.

Subjects will be recruited from the athletic department at WWU.

b. Describe how you will recruit a sample from your subject population, including possible use of compensation, and the number of subjects to be recruited.

The subject sample for this study will consist of 30 athletes who will be recruited from Western Washington University athletic department. Subjects will be included in the study only if they were actively involved in resistance training for at least 1 year prior to the start of the study. In addition, subjects were required to have at least 1 year of experience with plyometric training and must have taken part in plyometric activities at least 1 day per week. If the subjects

could not finish the testing, they were removed from the study. The subjects also had to be free of any musculoskeletal injuries or disorders in order to take part in the study.

5. Briefly describe the research methodology. Attach copies of all test instruments/questionnaires that will be used.

Introduction:

The goal of the study was to determine if 3 sets of a 6-second maximal isometric quarter squat protocol was sufficient at potentiating force and power variables in a countermovement jump. Optimal duration for PAP occurrence between 1-15 minutes was also a variable that was measured. Five dependent variables were measured to analyze the effect of a conditioning stimulus on PAP, which included MRFD, PRFD, RSI, PP, and ERFD. Two preliminary sessions were used for the subjects to become familiar with the protocol and also to become comfortable with countermovement jump testing on a force platform. The following session was used to test the effects of an isometric conditioning stimulus on CMJ characteristics including MRFD, PRFD, RSI, PP, and ERFD.

Description of subjects:

The subject sample consisted of 30 recreationally trained individuals who were actively involved in resistance training for at least 1 year prior to the start of the study. In addition, subjects were required to have at least 6 months experience and be actively involved in sports involving jumping or explosive type movements.

Design of Study:

The design of the study was a repeated measures design with all subjects being tested before and after a potentiating protocol.

Data Collection Procedures:

This protocol was approved by the committee for Human Subjects Protection at Western Washington University. All subjects were required to read and sign a hold harmless agreement and informed consent form. Data was collected in the Biomechanics Laboratory at Western Washington University. One preliminary session took place prior to testing in order to get acquainted with the procedures and to practice CMJ testing on a force platform. The second session took place in order to collect pre-testing values and practice the isometric quarter squat conditioning stimulus using the custom made apparatus. The third session included the isometric quarter squat conditioning stimulus followed by CMJs on an Advanced Mechanical Technology Inc. (AMTI; Watertown, MA) force platform which was used to measure ground reaction force (GRF). The force plate was set at a sampling rate of 1200 Hz and recorded five seconds of data. The subjects were instructed to stand on the force plate so their weight could be measured and recorded. The subjects were then asked to cross their arms across their chests so that their hands were grabbing their opposite shoulders. Subjects maintained this position throughout the CMJ. The technician performed the following countdown; “3, 2, 1, GO” (no information was provided

about form or technique of the CMJ). When the technician said "GO", the subjects performed a countermovement jump up and tried to jump as high and as quickly as possible. The Technician activated the trigger on the count of "1" so that there was one second of data preceding the CMJ.

The Custom Made Apparatus:

The isometric quarter squat was performed on a custom-made apparatus and the subjects were positioned such that the conditioning stimulus was performed in a quarter squat position. The apparatus consisted of a platform (to stand on) with two chains that extended from the floor edges of the platform to a bar that rested on the shoulders of the subjects. The chains of the apparatus were shortened or lengthened according to the subject's height via two carabiners.

Methods of First Session:

Upon entering the biomechanics laboratory, subjects were asked to sign an informed consent and hold harmless agreement. The subjects were then asked to fill out a questionnaire and take part in a familiarization phase. The questionnaire was used to record the subject's height (meters), body mass (kg), and activity level. The familiarization phase allowed the subjects to practice the standard warm-up protocol, three sets of the conditioning stimulus, and 6 CMJs with 1 minute rest in between. The warm-up consisted of 5 minutes of cycling at 300 kg*m/min, 10 lunges, 10 deep squats, and 10 light hops. The conditioning stimulus consisted of three 6-second isometric quarter squat which was achieved by pushing against the apparatus in an attempt to extend the hip, knee and ankle maximally. This standard warm-up protocol was used in all training sessions. All sessions were separated by 4 days to ensure the subjects were completely rested before the next session. Subjects were also asked to refrain from any high intensity exercise for at least 48 hours prior to the session.

Methods of the Second and Third Session:

The experimental and control condition were randomly selected for each subject over the second and third day. The condition that was not drawn of the second day was performed on the third day.

The Control Condition:

In the control condition, testing for CMJ performance was administered following the standardized warm-up. After completion of the warm-up, 5 minutes of active rest (walking) took place followed by 5 minutes of passive rest and pre-test measurements were taken. Subjects were then asked to stand in the middle of the force platform and perform a CMJ as far as possible in the vertical direction. Three pre-test maximal CMJs took place with 1 minute rest in between. At the end of the conditioning stimulus protocol, CMJ post-testing took place and consisted of a maximal CMJ at 1, 5, 10, and 15 minutes following the conditioning stimulus. The CMJ post-testing protocol remained consistent in both conditions. Following post-testing, the subjects were given a second time to become familiar with the apparatus for the conditioning stimulus. The conditioning stimulus consisted of three trials of a 6-second isometric quarter squat with 1 minute in between each.

The Experimental Condition:

In the third session, subjects were first asked to take part in the standardized warm-up. Following the warm-up, 5 minutes of active rest and 5 minutes of passive rest took place and pre-test measurements were taken. Subjects were then asked to perform three 6-second isometric quarter squat by pushing against the apparatus in an attempt to extend the hip, knee and ankle maximally. Each conditioning stimulus was separated by 1 minute rest in between. At the end of the conditioning stimulus protocol, the CMJ post-testing took place.

Data Analysis:

A custom made Labview program (National Instruments, Austin, TX) was used to determine MRFD, PRFD, RSI, and ERFD from the vertical GRF measured from the force platform. The mean rate of force development was determined by calculating the difference between the minimum and maximum vertical GRF (VGRF) divided by the time from minimum and maximum VGRF (McLellan, Lovell, & Gass, 2011). The peak rate of force development was determined by the maximum change in force over a 10-millisecond time intervals during the countermovement jump (Bompa & Haff, 2009). Reactive strength index was determined by jump height (meters) divided by time (seconds) to takeoff (Zatsiorsky & Kraemer, 2006). Eccentric rate of force development was determined by subtracting $vGRF_{min}$ at the bottom of the countermovement from $vGRF_{min}$ divided by the time duration.

Statistics:

One way repeated measures analysis of variance was used to examine the effect of time (pre-test, 1, 5, 10 and 15 minutes) on MRFD, PRFD, RSI, PP, and ERFD. Statistical significance was set to ($p < .01$) due to the Bonferroni correction from 5 dependent variables. Effect size was calculated using η^2 and evaluated the effect size according to the scale suggested by Field, 2013.

6. Give specific examples (with literature citations) for the use of your test instruments/questionnaires, or similar ones, in previous similar studies in your field.

N/A

7. Describe how your study design is appropriate to examine your question or specific hypothesis. Include a description of controls used, if any.

Biomechanically similar conditioning activities have been suggested to elicit PAP, and have been used in research to elicit PAP, however it is not clear whether this protocol is necessary. While it is necessary to potentiate musculature that is used in the potentiated exercise, it has not been determined whether it is necessary to make the conditioning contraction biomechanically similar. Research suggests that the intensity of the conditioning contraction is, instead, one of the major variables that should be considered and not the muscle action. Further research is necessary to determine if a biomechanically similar (muscle action type) conditioning contraction is necessary (Baudry & Duchateau, 2004; Guellich & Schmidtbleicher, 1996).

There are multiple studies that have used biomechanically similar potentiating exercises

to elicit PAP in both the type of activity and muscle action. However, some evidence suggests that a maximal muscle contraction and the activation of the maximal number of muscle fibers may be a more important variable for eliciting PAP than the biomechanical similarity of the conditioning contraction to the potentiated exercise (Baudry & Duchateau, 2004; Guellich & Schmidtbleicher, 1996). A maximal isometric contraction is a type of exercise that can allow for complete activation of muscle groups from a fixed muscle length. Based on previous results, this may be all that is necessary for the proper activation of PAP (Baudry & Duchateau, 2004; Guellich & Schmidtbleicher, 1996). However, the protocols used in these studies involved expensive equipment that may not be readily available to many athletes preparing for a maximum effort performance. There have not been no previous studies that have directly looked at whether a isometric conditioning stimulus is sufficient to elicit PAP. Therefore the effects of a isometric conditioning stimulus on countermovement jump performance is not yet known and can be assessed by the testing paradigm of the proposed protocol.

8. Give specific examples (with literature citations) for the use of your study design, or similar ones, in previous similar studies in your field.

A similar study was used in a study using 10 trained men to examine effects of multiple sets of a potentiating exercise on countermovement jump performance (Smilios et al., 2005). In another study by Baudry and Duchateau, 2004, nine subject's dorsiflexor muscles were tested for PAP potential using a custom made flootplate that allowed for concentric and eccentric muscle actions.

9. Describe the potential risks to the human subjects involved.

Multiple trials of the conditioning stimulus and countermovement jump protocol will be performed, therefore there is a risk of developing muscle fatigue. In addition, multiple days will take place which could result in delayed onset muscle soreness.

10. If the research involves potential risks, describe the safeguards that will be used to minimize such risks.

To minimize the risk of muscle fatigue, rest periods of at least one minute following the conditioning stimulus will be used. Four days will also be employed to minimize the risk of delayed onset muscle soreness between testing days.

11. Describe how you will address privacy and/or confidentiality.

All subjects will be assigned a distinctive subject number for both the control and experimental conditions. Only the primary investigator and his chair advisor will have access to information pertaining to the subjects' personal information. An example of a subject number that will be used in the study is displayed below:

PAPCC1

The code above indicates that this subject was involved in the current PAP study, that he or she

was taking part in the control condition (CC), and that he or she was the 1st subject (1).

12. If your research involves the use of schools (pre-kindergarten to university level) or other organizations (e.g., community clubs, companies), please attach a clearance eletter from an administrator from your research site indicating that you have been given permission to conduct this research. For pre-kindergarten to grade 12 level schools, an administrator (e.g. principal or higher) should issue the permission. For post-secondary level schools the class instructor may grant permission. For Western Washington university, this requirement of a clearance letter is waived if you are recruiting subjects from a scheduled class. If you are recruiting subjects from a campus group (not a class) at Western Washington University, you are required to obtain a clearance letter from a leader or coordinator of the group.

N/A

13. If your research involves the use of schools (pre-kindergarten to university level)or other organizations (e.g., community clubs, companies), and you plan to take still or video pictures as part of your research, please complete a) to d) below:

a. Who have you contacted at the school district or organization involved, to determine the policy on the use of photography in the school or organization?
b. Explain how your research plan conforms to the policy on the use of photography in the school or organization.
c. Attach a copy of the school district or organization policy on the use of photography at the schools or organization.
d. Explain how you will ensure that the only people recorded in your pictures will be the ones that have signed a consent form.

N/A

1. ***A current curriculum vitae.***

See attached

2. ***A copy of the certificate of completion for Human Subjects Training from the online human subjects training module, for each person involved in the research who will have any contact with the subjects or their data.***

See attached

3. ***If your subjects are required to turn in a physical clearance from priot to participation include a copy of the blank form.***

N/A

References:

1. Baechle, T. R., & Earle, R. W. (2008). Essentials of Strength Training and Conditioning (3rd ed.). Champaign, IL: Human Kinetics
2. Batista, M. A., Roschel, H., Barroso, R., Ugrinowitsch, C., & Tricoli, V. (2011). Influence of strength training background on postactivation potentiation response. *Journal of Strength and Conditioning Research, 25*(9), 2496-2502.
3. Baudry, S., & Duchateau, J. (2004). Postactivation potentiation in human muscle is not related to the type of maximal conditioning contraction. *Muscle and Nerve, 30,* 328-336. doi:10.1002/mus.20101
4. Baudry, S., & Duchateau, J. (2007a). Postactivation potentiation in a human muscle: Effect on the load-velocity relation of tetanic and voluntary shortening contractions. *Journal of Applied Physiology, 103*(4), 1318-1325.
5. Baudry, S., & Duchateau, J. (2007b). Postactivation potentiation in a human muscle: Effect on the rate of torque development of tetanic and voluntary isometric contractions. *Journal of Applied Physiology, 102*(4), 1394-1401.
6. Bompa, T. O., & Haff, G. G. (2009). *Periodization: Theory and Methodology of Training* (5th ed.). Champaign, IL: Human Kinetics.
7. Brandenburg, J. P. (2005). The acute effects of prior dynamic resistance exercise using different loads on subsequent upper-body explosive performance in resistance-trained men. *Journal of Strength and Conditioning Research, 19*(2), 427-432.
8. Brown, G. L., & von Euler, U. S. (1938). The after effects of a tetanus on mammalian muscle. *Journal of Physiology, 93*, 39-60.
9. Buchthal, F., & Schmalbruch, H. (1970). Contraction times of twitches evoked by H-reflexes. *Acta Physiologica Scandinavica,* 80(3), 378-82.
10. Capaday, C. (1997). Neurophysiological methods for studies of the motor system in freely moving human subjects. *Journal of Neuroscience Methods,* 74(2), 201-218.
11. Close, R., & Hoh, J. F. (1968). The after-effects of repetitive stimulation on the isometric twitch contraction of rat fast skeletal muscle. *The Journal of Physiology,* 197(2), 461-477.
12. Ebben, W. P., & Watts, P. B. (1998). A review of combined weight training and plyometric training modes: Complex training. *Strength and Conditioning,* 20(5), 18-27.
13. Field, A. (2013). *Discovering statistics using IBM SPSS statistics* (4th ed.). Thousand Oaks, CA: Sage.
14. French, D. N., Kraemer, W. J., & Cooke, C. B. (2003). Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *Journal of Strength and Conditioning Research,* 17(4), 678-685.
15. Folland, J. P., Wakamatsu, T., Fimland, M. S. (2008). The influence of maximal isometric activity on twitch and H-reflex potentiation, and quadriceps femoris performance. *European Journal of Applied Physiology, 104,* 739-748. doi: 10.1007/s00421-008-0823-6

16. Gallagher, P. J., Herring, B. P., & Stull, J. T. (1997). Myosin light chain kinases. *Journal of Muscle Research and Cell Motility*, 18(1), 1-16.
17. Garner, S. H., Hicks, A. L., & McComas, A. J. (1989). Prolongation of twitch potentiating mechanism throughout muscle fatigue and recovery. *Experimental Neurology*, 103(3), 277-281.
18. Gilbert, G., & Lees, A. (2005). Changes in the force development characteristics of muscle following repeated maximum force and power exercise. *Ergonomics, 48*, 1576-1584.
19. Gordon, A. M., Homsher, E., & Regnier, M. (2000). Regulation of contraction in striated muscle. *Physiological Reviews, 80*(2), 853-924.
20. Gossen, E. R., & Sale, D. G. (2000). Effect of postactivation potentiation on dynamic knee extension performance. *European Journal of Applied Physiology, 83*(6), 524-30.
21. Guellich, A., & Schmidtbleicher, D. (1996). MVC-induced short-term potentiation of explosive force. *New Studies in Athletics, 11*(4), 67-84.
22. Hamada, T., Sale, D. G., MacDougall, J. D., & Tarnopolsky, M. A. (2000). Postactivation potentiation, fiber type, and twitch contraction time in human knee extensor muscles. *Journal of Applied Physiology, 88*(6), 2131-2137.
23. Hilfiker, R., Hübner, K., Lorenz, T., & Marti, B. (2007). Effects of drop jumps added to the warm-up of elite sport athletes with a high capacity for explosive force development. *Journal of Strength and Conditioning Research, 21*(2), 550-555.
24. Kilduff, L. P., Bevan, H. R., Kingsley, M. I., Owen, N. J., Bennett, M. A., Bunce, P. J., Hore, A. M., ... Cunningham, D. J. (2007). Postactivation potentiation in professional rugby players: Optimal recovery. *Journal of Strength and Conditioning Research*, 21(4), 1134-1138.
25. Klein, C. S., Ivanova, T. D., Rice, C. L., & Garland, S. J. (2001). Motor unit discharge rate following twitch potentiation in human triceps brachii muscle. *Neuroscience Letters*, 316(3), 153-156.
26. Lowey, S., & Trybus, K. M. (2010). Common structural motifs for the regulation of divergent class II myosins. *Journal of Biological Chemistry*, 285(22), 16403-16407.
27. Luca, C. J. D., Foley, P. J., & Erin, Z. (1996). Motor unit control properties in constant-force isometric contractions. *Journal of Neurophysiology*, 76(3), 1503-1516.
28. Mangus, B. C., Takahashi, M., Mercer, J. A., Holcomb, W. R., McWhorter, J. W., & Sanchez, R. (2006). Investigation of vertical jump performance after completing heavy squat exercises. *Journal of Strength and Conditioning Research, 20*(3), 597-600.
29. McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011). The role of rate of force development on vertical jump performance. *Journal of Strength and Conditioning Research, 25*(2), 379-385.
30. Moore, R. L., & Stull, J. T. (1984). Myosin light chain phosphorylation in fast and slow skeletal muscles in situ. *The American Journal of Physiology*, 247(5), 462-471.

31. O'Leary, D. D., Hope, K., & Sale, D. G. (1997). Posttetanic potentiation of human dorsiflexors. *Journal of Applied Physiology,* 83(6), 2131-2138.
32. Padre, R. C., & Stull, J. T. (2000a). Conformational requirements for Ca(2+)/calmodulin binding and activation of myosin light chain kinase. *FEBS Letters, 472*(1), 148-152.
33. Padre, R. C., & Stull, J. T. (2000b). Functional assembly of fragments from bisected smooth muscle myosin light chain kinase. *The Journal of Biological Chemistry,* 275(35), 26665-26673.
34. Palmer, B. M., & Moore, R. L. (1989). Myosin light chain phosphorylation and tension potentiation in mouse skeletal muscle. *The American Journal of Physiology,* 257(5), 1012-1019.
35. Palmieri, R. M., Ingersoll, C. D., Hoffman, M. A. (2004). The hoffman reflex: Methodologic considerations and applications for use in sports medicine and athletic training research. *Journal of Athletic Training, 39*(3), 268-277.
36. Rassier, D. E., & Macintosh, B. R. (2000). Coexistence of potentiation and fatigue in skeletal muscle. *Brazilian Journal of Medical and Biological Research, 33*(5), 499-508.
37. Robbins, D. W. (2005). Postactivation potentiation and its practical applicability: A brief review. *Journal of Strength and Conditioning Research,* 19(2), 453-458.
38. Robertson, D. G. E., Caldwell, G. E., Hamill, J., Kamen, G., & Whittlesey, S. N. (2004). *Research Methods in Biomechanics*. Champaign, IL: Human Kinetics.
39. Scott, S. L., & Docherty, D. (2004). Acute effects of heavy preloading on vertical and horizontal jump performance. *Journal of Strength and Conditioning Research,* 18(2), 201-205.
40. Smilios, I., Pilianidis, T., Sotiropoulos, K., Antonakis, M., & Tokmakidis, S. P. (2005). Short-term effects of selected exercise and load in contrast training on vertical jump performance. *Journal of Strength and Conditioning Research,* 19(1), 135-139.
41. Smith, J. C., & Fry, A. C. (2007). Effects of a ten-second maximum voluntary contraction on regulatory myosin light-chain phosphorylation and dynamic performance measures. *Journal of Strength and Conditioning,* 21(1), 73-76.
42. Stull, J. T., Kamm, K. E., & Vandenboom, R. (2011). Myosin light chain kinase and the role of myosin light chain phosphorylation in skeletal muscle. *Archives of Biochemistry and Biophysics, 510*(2), 120-128.
43. Szczesna, D., Zhao, J., Jones, M., Zhi, G., Stull, J., & Potter, J. D. (2002). Phosphorylation of the regulatory light chains of myosin affects Ca2+ sensitivity of skeletal muscle contraction. *Journal of Applied Physiology,* 92(4), 1661-1670.
44. Till, K. A., & Cooke, C. (2009). The effects of postactivation potentiation on sprint and jump performance of male academy soccer players. *Journal of Strength and Conditioning Research, 23*(7), 1960-1967.
45. Tillin, N., & Bishop, D. (2009). Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Medicine,* 39(2), 147-166.

46. Wilson, J. M., Kunkan, N. M., Marin, P. J., Brown, L. E., Loenneke, J. P., Winson, S. M. C., Jo, E., … Ugrinowitsch, C. (2013). Meta-analysis of postactivation potentiation and power: Effects of conditioning activity, volume, gender, rest periods, and training status. *Journal of Strength and Conditioning Research, 27*(3), 854-859.
47. Yetter, M., & Moir, G. L. (2008). The acute effects of heavy back and front squats on speed during forty-meter sprint trials. *Journal of Strength and Conditioning Research, 22*(1), 159-165.
48. Zatsiorsky, V. M., & Kraemer, W. J. (2006). *Science and Practice of Strength Training* (2nd ed.) Champaign, IL: Human Kinetics.
49. Zehr, E. P. (2002). Considerations for use of the Hoffmann reflex in exercise studies. *European Journal of Applied Physiology,* 86(6), 455-468
50. Zhi, G., Ryder, J. W., Huang, J., Ding, P., Chen, Y., Zhao, Y., Kamm, K. E., ... Stull, J. T. (2005). Myosin light chain kinase and myosin phosphorylation effect frequency-dependent potentiation of skeletal muscle contraction. *Proceedings of the National Academy of Sciences of the United States of America,* 102(48), 17519-17524.

Appendix B

Informed Consent
Western Washington University
Consent to Take Part in a Research Study

Project: The Effects of an isometric quarter squat on countermovement jump performance

You have been asked to participate in a study conducted by Mitchell Dropp, CSCS, Graduate Student from the department of Physical Education, Health, and Recreation at the Western Washington University. The purpose of this investigation is to determine the effect of a conditioning stimulus on vertical jump performance. You have been selected to take part in the study because you have no history of musculoskeletal injuries and have participated in plyometric training at least 1 day per week for the past year.

In order to participate, it is imperative that you understand that the following information. You will be asked to fill out a brief form which will provide researchers with basic information including age, height and your current activity level. Non-invasive measurements will be made throughout the experiment using a force plate embedded into the floor. To perform these measurements, you will be asked to stand and perform explosive jumps on the force plate upon command of the researcher. You will then be asked to actively perform a maximal isometric quarter squat against a custom made apparatus that will be fitted to your body height 3 times for 6 seconds for a total of 18 seconds. Following the isometric quarter squat exercise, you will be asked to attempt 3 more explosive jumps on a force plate on upon command from the researcher. This will be performed over a period of 15 minutes. The entire testing process should take 60-90 minutes per session for three testing sessions each separated by four days of rest.

There is no direct benefit to individuals participating in the current study. However, information collected from the participants of the current study will help to deepen our understanding of methods for improving performance in athletic movements.

In any research study, an individual's participation carries with it possible risks. Since multiple attempts of maximal jumps will be executed, there is a risk of muscular fatigue and delayed onset muscle soreness. However, ample rest will be afforded between attempts. In addition, you will be monitored by a certified strength and conditioning specialist and every precaution will be taken to minimize these risks. At any point during the study under any circumstance, you are free to discontinue your participation in the current study.

All information obtained that can be identified with you in the current study will remain confidential and will not be disclosed without your permission. All subject names and identities will be kept confidential by assigning identification numbers, rather than using names. Upon approval by you via written consent, you may be contacted in the future as a follow-up regarding this project.

Your participation is completely voluntary. The decision as to whether to participate in the current study will not affect your association with Western Washington University. If you decide to take

part in the study, you are free to withdraw your consent and discontinue your participation at any time under any circumstance without any penalty.

If you have any questions regarding the project procedures, please feel free to contact Dave Suprak, PhD, ATC, CSCS (360) 650-2586, Department of Physical Education, Health and Recreation, Western Washington University, Bellingham, WA, 98225. If you have questions regarding your rights as a research participant, or if you should experience any research-related injuries, please contact Janai Symons, (360) 650-3082, Office of Research and Sponsored Programs, Western Washington University, Bellingham, WA, 98225. You will be provided with a copy of this form for your safe keeping.

Your signature states that you have read and understood all the information provided above, that you willingly agree to volunteer your time, that you are free to withdraw your consent at any time and discontinue participation at any time without any penalty, and that you are not waiving any legal claims, rights or remedies. Your signature below also states that you are 18 years of age or older.

Print Name: _____

Signature: _____ Date: _____

Researchers Signature: _____ Date: _____

Appendix C

Research Protocol Checklist and Data Logging

Subject #:
Day 1: (Date:)
Sign information:

- ☐ Informed consent and hold harmless agreement

Questionnaire:

- ☐ Height
- ☐ Age
- ☐ Body Mass
- ☐ Activity Level

Warm-up:

- ☐ 5 min cycling at 300 kg*m/min
- ☐ 10 Lunges
- ☐ 10 Deep Squats
- ☐ 10 Light Hops

Conditioning Stimulus:

- ☐ Adjust apparatus to correct size **(# of rings:)**
- ☐ 3 sets of 6-second isometric quarter squat

Prep for next session:

- ☐ Set up time for day 2
    - Make sure it is 4 days from date above
- ☐ Make sure subject knows to refrain from any high intensity exercise for at least 48 hours prior to the session

Draw from box:

- ☐ Experimental **(Day #:)**
- ☐ Control **(Day #:)**

Control: (Date: ;Total Time:)

Warm-up:

- 5 min cycling at 300 kg*m/min
- 10 Lunges
- 10 Deep Squats
- 10 Light Hops

Rest:

- 5 min walking
- 5 min passive

Pre-test Measurements:

- 3 CMJ spaced 1 min apart
- **0, 1 min, 2 min**

Rest:

- **3 min 48sec**

Post-Testing:

- CMJ at: 1 min, 5 min, 10 min, and 15 min
- **5:48, 9:48, 14:48, 19:48**

Prep for next session:

- Set up time for day 2
    - Make sure it is 4 days from date above

- Make sure subject knows to refrain from any high intensity exercise for at least 48 hours prior to the session

Experimental: (Date: ;Total Time:)

Warm-up:

- 5 min cycling at 300 kg*m/min
- 10 Lunges
- 10 Deep Squats
- 10 Light Hops

Rest:

- 5 min walking
- 5 min passive

Pre-test Measurements:

- 3 CMJ spaced 1 min apart
- **0, 1 min, 2 min**

Conditioning Stimulus:

- Adjust apparatus to correct size
- 3 sets of 6-second isometric quarter squat spaced 1 min apart
- **2:30, 3:36, 4:42** (End at 4:48)

Post-Testing:

- CMJ at: 1 min, 5 min, 10 min, and 15 min
- **5:48, 9:48, 14:48, 19:48**

Appendix D

Table 2.

Raw Data for Subject Characteristics

Sub #	Age	Sex	Height	Body Bass
1	22	F	185.42	74.17
2		F	172.72	79.73
3	24	M	187.96	83.13
4	24	F	152.4	59.27
5	22	F	157.48	51.73
6	24	F	160.2	57.19
7	24	F	162.56	59.08
8	22	F	165.1	66.41
9	22	M	170.18	77.62
10	21	M	187.96	65.98
11	22	M	172.72	71.89
12	22	M	187.96	81.17
13	26	M	182.88	97.45
14	23	M	175.26	90.79
15	23	M	180.34	74.45
16	19	F	157.48	67.52
17	28	M	180.34	78.08
18	21	F	180.34	60.33
19	22	F	165.1	62.12
20	26	M	170.18	81.47
21	21	M	180.34	63.5
22	22	F	175.26	61.23
23	22	F	175.26	78.77

Table 3.

Raw Data for ERFD Control Trials

	Control				
Sub #	Pre	1_min	5_min	10_min	15_min
1	3326.05	2937.52	3347.29	3379.02	3027.44
2	2422	2034.48	2050.67	2169.56	1839.72
3	7350.69	6284.03	7554.15	7437.34	5752.95
4	3968.6	4567.55	4100.69	3998.01	4186.96
5	2447.98	1810.89	2003.84	2096.94	2068.41
6	2009.15	2283.86	2426.25	2333.29	2383.46
7	2086.43	2021.07	2585.67	2005.05	2208.33
8	3292.53	3086.7	2885.57	2611.22	2311.15
9	3962.03	3040.36	2746.29	3165.99	3956.03
10	3441.68	2679.13		2423.8	3355.08
11	7907.86	7067.15	7193.84	7583.18	7828.59
12	17237.37	9421.15	10095.29	12872.33	12229.38
13	8763.35	7768.68	15098	7192.33	10367.05
14	4731.3	3466.33	2304.68	3589.19	3492.76
15	4433.59	5187.52	4318.08	4662.09	4920.83
16	2637.49	2088.78	2609.53	1877.19	2232.28
17	2283.41	2181.12	1238.95	2232.15	2218.8
18	2264.91	1945.85	2027.18	1943.03	2397.57
19	3573.41	3404.69	3662.52	2596.56	3149.02
20	3956.68	3784.63	4330.71	3835.56	2699.08
21	2670.64	2850.11	2591.67	2129.33	2009.35
22	3212.86	3124.86	3036.74	3165.04	3132.54
23	1913.92	2050.35	1943.74	1894.43	1954.43

Table 4.

Raw Data for Experimental ERFD

	Experimental				
Sub #	Pre	1_min	5_min	10_min	15_min
1	4010.12	3638.64	3766.43	3402.59	3671.94
2	2119.07	2256.64	2398.28	2681.47	2637.67
3	4814.28	4380.49	4199.44	3818.13	5023.84
4	4327.58	3557.34	5182.04	4191.37	4808.28
5	2366.95	2071.48	1811.63	1970.88	
6	2356.32	2918.25	2286.08	2537.62	1984.92
7	1478.21	1481.73	1193.19	1560.22	1598.92
8	3393.93	2100.3	3474.23	4594.28	3170.06
9	2907.63	3581.99	3692.82	4023.03	3409.33
10	2386.53	3276.59	2594.78	3202.3	2986.12
11	6493.65	6740.36	6550.45	6842.39	6757.74
12	9137.69	16179.09	13906.93		12919.68
13	8613.61	9692.54	10591.39	8485.85	8936.7
14	2577.77	3260.15	4088.7	3825.01	2659.99
15	4675.7	3897.35	4545.17	4344.53	4902.41
16	2736.62	2097.77	2592.59	2181.14	2287.58
17	2651.95	2720.96	1961.89	2518.06	2188.97
18	2796.44	2821.66	3015.99	2843.31	2610.29
19	3323.29	2983.24	6710.16	3417.41	3156.23
20	2687.96	3769.42	3755.11	3508.35	3300.49
21	2167.19	2220.02	2598.84	1942.75	1956.63
22	3169.68	2944.28	3008.03	2880.26	3082.21
23	1548.44	1601.3	1572.01	1982.25	1658.27

Table 5.

Raw Data for Control MRFD

	Control				
Sub #	Pre	1_min	5_min	10_min	15_min
1	3525.11	3339.02	3725.98	3495.6	3099.27
2	1688.32	1524.1	1435.76	1493.13	1303.25
3	7653.62	6652.71	7685.3	7298.13	5785
4	3477.83	5558.84	2681.64	2480.64	4939.77
5	2537.87	1887.65	2048.1	2151.8	2134.42
6	1937.3	2414.43	2620.1	2344.54	2514.14
7	2050.87	2345.61	3269.08	1987.97	2309.68
8	3437.58	3316.88	3116.77	2645.52	2355.29
9	3075.19	2132.67	2016.43	2363.41	2807.13
10	2564.49	2142.72	2187.7	1969.58	2320.94
11	7182.2	6848.48	6569.69	6674.53	7113.99
12	21877.51	13385.13	19141.34	20379.19	19705.68
13	8145.48	6725.9	14054.48	6734.19	9328.6
14	5254.65	4581.14	3808.35	4221.74	4411.59
15	4694.35	5530.9	4452.43	4846.27	5020.42
16	2600.06	2066.65	2539	1835.82	2200.18
17	2128.28	1892.53	1422.07	1931.23	1773.15
18	2270.03	1944.91	2038.87	1953.83	2422.3
19	3702.09	3413.24	3712.04	2919.59	3149.53
20	3516.81	2754.35	4298	2613.56	1833.7
21	1798.91	1918.39	1746.77	1633.93	1510.38
22	2548.89	1922.87	3127.5	3236.5	3227.38
23	1217.18	1165.34	1181.38	1172.87	1207.7

Table 6.

Raw Data for Experimental MRFD

	Experimental				
Sub #	Pre	1_min	5_min	10_min	15_min
1	4450.35	4164.97	4087.13	3731.7	4108.66
2	1420.26	1437.9	1553.36	2987.92	1536.27
3	4871.82	4378.19	4248.31	3850.83	5327.06
4	4003.51	2477.35	3249.82	2502.92	5038.28
5	2515.72	2362.97	1120.93	2034.84	2279.55
6	2498.4	1697.59	1453.08	2694.94	1234.01
7	1233.34	1253.51	1194.33	1267.2	1251.97
8	3397.5	2102.8	3423.19	5395.57	3134.59
9	2026.72	3604.66	2381.05	4316.08	2233.82
10	1931.47	2233.6	2006.28	2245.65	2434.01
11	5770.27	6266.42	6044.32	6249.89	6222.36
12	11157.4	18319.32	24456.99		18784.35
13	8073.1	8807.17	9536.65	7863.82	8368.82
14	3927.07	4151.95	4756.44	4641.02	4692.01
15	4847.58	4077.1	4974.82	4509.39	5148.36
16	3250.52	2067.16	2547.81	2197.95	2353.59
17	2041.64	2282.72	1861.32	2096.94	1891.5
18	2819.3	2906.8	3074.9	2878.9	2615.62
19	3195.49	2952.82	2889.8	3559.01	3156.74
20	2222.72	2724.41	2827.09	2507.29	2157.91
21	1541.95	1550.29	1749.25	1456.13	1390.41
22	3358.04	3047.95	3199.25	2861.49	3097.03
23	1138.76	1200.45	1126.1	1298.25	1160.82

Table 7.

Raw Data for Control PRFD

	Control				
Sub #	Pre	1_min	5_min	10_min	15_min
1	8258.73	6710.22	8000.65	6968.31	6194.05
2	6022	4387.45	4645.54	5677.88	3871.28
3	14968.95	11871.93	14710.87	15227.04	9549.17
4	8688.88	18065.98	12904.27	10065.33	15227.04
5	3699.23	2838.94	3355.12	3355.12	3097.02
6	5677.88	5677.88	4387.46	4903.62	4645.54
7	5075.68	5677.88	5677.88	4129.38	4645.54
8	6280.08	6452.14	5161.72	5161.72	5419.8
9	8172.71	5935.97	5419.8	6452.14	5935.97
10	11011.65	12646.18	6452.14	12388.1	4903.62
11	19700.52	16259.38	14710.86	21679.18	27873.23
12	42239.99	36131.96	38970.9	42326.02	36131.96
13	15485.13	12130.02	60908.16	11613.85	19614.49
14	12732.22	10065.33	13678.53	8774.91	9549.17
15	9377.11	11355.77	7226.39	8516.82	8516.82
16	4817.6	3355.12	4387.46	4645.54	4387.46
17	7312.42	4903.62	6452.14	6194.05	6710.22
18	5505.83	5677.88	7742.57	6194.06	5935.97
19	7226.39	7484.48	6710.22	6710.22	6452.14
20	6108.02	6194.05	7484.48	6194.06	4903.62
21	6624.19	5935.97	4129.38	3355.12	4387.45
22	6882.28	7226.39	5935.96	5935.97	7226.4
23	4473.49	4129.37	4645.54	4387.46	4129.37

Table 8.

Raw Data for Experimental PRFD

	Experimental				
Sub #	Pre	1_min	5_min	10_min	15_min
1	9291.08	8000.65	9807.25	7484.47	7484.48
2	5161.71	4645.54	6194.05	5677.88	5935.97
3	10323.42	7226.4	7484.47	6968.31	7742.57
4	16603.5	7484.48	19614.5	8774.91	18840.24
5	7742.57	8516.82	4645.54	3355.12	
6	6021.99	9549.17	5161.71	4903.62	4387.46
7	3785.25	4129.38	3097.03	4129.37	4129.38
8	5505.83	4903.62	7484.47	8774.91	6968.31
9	5333.77	5419.79	7484.48	6710.22	6968.31
10	9635.19	9807.25	6194.05	13420.44	5677.88
11	15829.24	16259.39	13936.62	13678.53	14968.96
12	38454.73	30970.26	86200.53		32776.86
13	17119.67	22195.35	17033.64	12388.11	19356.41
14	12818.24	10065.33	12904.27	9549.16	16517.47
15	8946.96	8000.65	10323.42	8000.65	8774.91
16	33465.08	4645.54	4387.46	3613.2	4129.37
17	6538.17	8258.73	5935.97	7742.57	9032.99
18	6882.28	5935.97	5677.88	6194.05	5161.71
19	6022	6710.22	6452.13	6452.14	6194.06
20	5419.8	7226.4	5419.8	5419.8	6194.05
21	3785.26	4129.38	4387.45	3871.28	3355.12
22	8344.76	7484.48	6710.22	6452.14	7742.56
23	4043.34	3355.12	4387.46	3871.28	3355.12

Table 9.

Raw Data for Control RSI

	Control				
Sub #	Pre	1_min	5_min	10_min	15_min
1	0.21	0.19	0.2	0.18	0.17
2	0.22	0.21	0.19	0.22	0.16
3	0.52	0.42	0.58	0.43	0.43
4	0.34	0.3	0.33	0.28	0.31
5	0.22	0.2	0.19	0.19	0.23
6	0.16	0.15	0.16	0.17	0.14
7	0.19	0.17	0.17	0.17	0.19
8	0.18	0.19	0.15	0.16	0.16
9	0.43	0.38	0.34	0.43	0.34
10	0.53	0.51		0.48	
11	0.79	0.79	0.82	0.59	0.77
12	0.6	0.54	0.58	0.53	0.52
13	0.62	0.56	0.7	0.49	0.54
14	0.86	0.37	0.35	0.39	0.32
15	0.42	0.37	0.4	0.32	0.36
16	0.22	0.24	0.2	0.17	0.18
17	0.31	0.36	0.32	0.3	0.3
18	0.18	0.2	0.22	0.18	0.17
19	0.25	0.19	0.22	0.24	0.24
20	0.41	0.4	0.41	0.45	0.32
21	0.39	0.44	0.35	0.37	0.3
22	0.31	0.27	0.27	0.27	0.24
23	0.19	0.13	0.17	0.18	0.17

Table 10.

Raw Data for Experimental RSI

	Experimental				
Sub #	Pre	1_min	5_min	10_min	15_min
1	0.22	0.18	0.18	0.19	0.16
2	0.2	0.18	0.21	0.22	0.19
3	0.4	0.4	0.37	0.37	0.38
4	0.3	0.41	0.37	0.33	0.38
5	0.21	0.23	0.17	0.19	
6	0.18	0.19	0.19	0.17	0.15
7	0.18	0.18	0.16	0.19	0.15
8	0.21	0.15	0.22	0.22	0.23
9	0.41	0.38	0.42	0.42	0.43
10	0.48	0.47	0.48	0.49	0.52
11	0.65	0.68	0.65	0.71	0.94
12	0.49	0.65	0.32	0.06	0.58
13	0.6	0.53	0.6	0.52	0.65
14	0.39	0.34	0.42	0.53	0.37
15	0.41	0.44	0.41	0.37	0.43
16	0.15	0.22	0.21	0.2	0.19
17	0.36	0.34	0.34	0.33	0.32
18	0.21	0.18	0.17	0.19	0.18
19		0.4		0.24	0.22
20	0.34	0.4	0.38	0.37	0.39
21	0.31	0.32	0.36	0.33	0.27
22	0.28	0.24	0.23	0.24	0.26
23	0.22	0.22	0.2	0.19	0.19

Table 11.

Raw Data for Control PP

	Control				
Sub #	Pre	1_min	5_min	10_min	15_min
1	2498.22	2452.65	2468.65	2405.7	2375.67
2	3230.96	3084.92	2766.84	3056.05	2862.8
3	4603.39	4424.06	4613.78	4675.97	4308.34
4	2653.6	2662.63	2728.9	2722.93	2558.81
5	1980.18	1938.48	1864.58	1884.84	1881.78
6	1866.91	1777.16	1847.58	1830.81	1799.71
7	2188.75	2090.93	2096.76	2089.65	2112.92
8	2198.41	2133.48	2048.87	2084.89	2079.64
9	4457.38	4252.17	4356.32	4306.6	4291.43
10	4723.82	4573.05	7205.69	4333.33	6013.45
11	6104.66	5995.26	6011.98	6160.92	5985.98
12	4745.41	4369.81	4365.01	4353.34	4328.33
13	6451.61	6344.68	6137.48	5979.5	6289.51
14	4800.92	4682.16	4513.3	4479.32	4453.91
15	4068.99	3709.54	3879.93	3609.88	3787.3
16	2383.19	2442.4	2286.6	2263.17	2240.93
17	4601.32	4647.75	4548.18	4389.65	4300.29
18	2028.5	1978.34	1987.87	1935.44	1840.27
19	2508.48	2409.13	2345.69	2276.15	2230.13
20	4366.37	4339.75	4109.15	4213.22	4171.58
21	3590.8	3507.38	3409.63	3580.96	3452.32
22	2410.24	2312.94	2250.81	2230.7	2288.98
23	2932.08	2538.98	2777	2793.38	2750.37

Table 12.

Raw Data for Experimental PP

	Experimental				
Sub #	Pre	1_min	5_min	10_min	15_min
1	2560.33	2477.29	2300.07	2391.14	2286.56
2	3065.13	3103.3	3082.51	2990.22	2781.62
3	4395.66	4479.31	4402.35	4350.64	4292.88
4	2475.97	2810.49	2763.91	2682.19	2716
5	1937.69	2081.88	1733.43	1932.08	
6	1919.79	1964.6	2001.22	1858.17	1821.11
7	2128.14	2225.13	2105.12	2187.81	2043.17
8	2193.98	2146.86	2200.79	2068.97	2169.08
9	4257.78	4273.33	4390.79	4309.3	4135.13
10	4421.03	4329.47	4395.64	4333.47	4391.1
11	5936.48	5990.43	5868.24	5937.36	5871.93
12	4918.86	5023.21	5138.5		4859.75
13	6170.62	6129.61	6529.88	6297.04	5953.92
14	4879.64	4633.46	5058.98	5127.3	4626.11
15	4344.2	4117.92	4082.24	3927.6	4111.9
16	2378.62	2328.19	2367.93	2354	2205.42
17	4474.81	4478.02	4506.81	4467.91	4417.68
18	2008.62	1962.76	1948.6	1901.68	1895.53
19	4472.11	2664.94	3793.21	2368.33	2341.41
20	4123.42	4206.83	4342.77	3979.31	4058.63
21	3377.77	3651.25	3618.96	3582.26	3405.87
22	2356.22	2182.55	2301.1	2234.16	2202.62
23	3005.61	2907.46	2862.87	2827.41	2786.87

Appendix E

Statistical Analysis Tables

2-Way Repeated Measures ANOVA

General Linear Model

Within-Subjects Factors

Measure: ERFD

Condition	Time	Dependent Variable
1	1	Pre_Cont
	2	Post1_Cont
	3	Post5_Cont
	4	Post10_Cont
	5	Post15_Cont
2	1	Pre_Exp
	2	Post1_Exp
	3	Post5_Exp
	4	Post10_Exp
	5	Post15_Exp

Descriptive Statistics

	Mean	Std. Deviation	N
Pre_Cont	3838.34	1989.401	20
Post1_Cont	3558.78	1747.629	20
Post5_Cont	3902.61	3087.514	20
Post10_Cont	3489.98	1861.772	20
Post15_Cont	3603.42	2185.313	20
Pre_Exp	3442.47	1713.666	20
Post1_Exp	3433.22	1872.520	20
Post5_Exp	3859.14	2157.646	20
Post10_Exp	3579.00	1660.649	20
Post15_Exp	3490.12	1831.901	20

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Condition	Pillai's Trace	.029	.567[b]	1.000	19.000	.461	.029	.567	.030
	Wilks' Lambda	.971	.567[b]	1.000	19.000	.461	.029	.567	.030
	Hotelling's Trace	.030	.567[b]	1.000	19.000	.461	.029	.567	.030
	Roy's Largest Root	.030	.567[b]	1.000	19.000	.461	.029	.567	.030
Time	Pillai's Trace	.290	1.634[b]	4.000	16.000	.214	.290	6.536	.159
	Wilks' Lambda	.710	1.634[b]	4.000	16.000	.214	.290	6.536	.159
	Hotelling's Trace	.409	1.634[b]	4.000	16.000	.214	.290	6.536	.159
	Roy's Largest Root	.409	1.634[b]	4.000	16.000	.214	.290	6.536	.159
Condition * Time	Pillai's Trace	.280	1.553[b]	4.000	16.000	.235	.280	6.212	.148
	Wilks' Lambda	.720	1.553[b]	4.000	16.000	.235	.280	6.212	.148
	Hotelling's Trace	.388	1.553[b]	4.000	16.000	.235	.280	6.212	.148
	Roy's Largest Root	.388	1.553[b]	4.000	16.000	.235	.280	6.212	.148

a. Design: Intercept

Within Subjects Design: Condition + Time + Condition * Time

b. Exact statistic

c. Computed using alpha = .01

Mauchly's Test of Sphericity[a]

Measure: ERFD

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	1.000	.000	0	.	1.000	1.000	1.000
Time	.018	70.139	9	.000	.335	.351	.250
Condition * Time	.236	25.156	9	.003	.561	.640	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Condition + Time + Condition * Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: ERFD

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	694248.234	1	694248.234	.567	.461	.029	.567	.030
	Greenhouse-Geisser	694248.234	1.000	694248.234	.567	.461	.029	.567	.030
	Huynh-Feldt	694248.234	1.000	694248.234	.567	.461	.029	.567	.030
	Lower-bound	694248.234	1.000	694248.234	.567	.461	.029	.567	.030
Error(Condition)	Sphericity Assumed	23259683.818	19	1224193.885					
	Greenhouse-Geisser	23259683.818	19.000	1224193.885					
	Huynh-Feldt	23259683.818	19.000	1224193.885					
	Lower-bound	23259683.818	19.000	1224193.885					
Time	Sphericity Assumed	3860913.786	4	965228.447	1.756	.146	.085	7.026	.272
	Greenhouse-Geisser	3860913.786	1.340	2880707.108	1.756	.198	.085	2.354	.107
	Huynh-Feldt	3860913.786	1.405	2748713.204	1.756	.197	.085	2.467	.111
	Lower-bound	3860913.786	1.000	3860913.786	1.756	.201	.085	1.756	.087
Error(Time)	Sphericity Assumed	41765332.129	76	549543.844					
	Greenhouse-Geisser	41765332.129	25.465	1640103.815					
	Huynh-Feldt	41765332.129	26.688	1564954.312					
	Lower-bound	41765332.129	19.000	2198175.375					
Condition * Time	Sphericity Assumed	1257059.765	4	314264.941	.750	.561	.038	3.000	.084
	Greenhouse-Geisser	1257059.765	2.246	559776.984	.750	.493	.038	1.684	.057
	Huynh-Feldt	1257059.765	2.561	490790.365	.750	.508	.038	1.921	.062
	Lower-bound	1257059.765	1.000	1257059.765	.750	.397	.038	.750	.038
Error (Condition*Time)	Sphericity Assumed	31842818.464	76	418984.453					
	Greenhouse-Geisser	31842818.464	42.667	746306.135					
	Huynh-Feldt	31842818.464	48.665	654331.762					
	Lower-bound	31842818.464	19.000	1675937.814					

a. Computed using alpha = .01

Tests of Within-Subjects Contrasts

Measure: ERFD

Source	Condition	Time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Linear		694248.234	1	694248.234	.567	.461	.029	.567	.030
Error(Condition)	Linear		23259683.818	19	1224193.885					
Time		Linear	88552.993	1	88552.993	.919	.350	.046	.919	.045
		Quadratic	498941.974	1	498941.974	1.204	.286	.060	1.204	.058
		Cubic	116436.480	1	116436.480	.584	.454	.030	.584	.031
		Order 4	3156982.339	1	3156982.339	2.121	.162	.100	2.121	.107
Error(Time)		Linear	1830974.077	19	96367.057					
		Quadratic	7871529.248	19	414291.013					
		Cubic	3787368.552	19	199335.187					
		Order 4	28275460.252	19	1488182.119					
Condition * Time	Linear	Linear	607999.692	1	607999.692	3.532	.076	.157	3.532	.196
		Quadratic	571977.446	1	571977.446	1.339	.262	.066	1.339	.065
		Cubic	21487.807	1	21487.807	.102	.753	.005	.102	.013
		Order 4	55594.821	1	55594.821	.064	.803	.003	.064	.012
Error (Condition*Time)	Linear	Linear	3270474.963	19	172130.261					
		Quadratic	8119012.787	19	427316.462					
		Cubic	3996312.075	19	210332.214					
		Order 4	16457018.638	19	866158.876					

a. Computed using alpha = .01

Tests of Between-Subjects Effects

Measure: ERFD

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	2620458967.471	1	2620458967.471	71.015	.000	.789	71.015	1.000
Error	701103543.356	19	36900186.492					

a. Computed using alpha = .01

Estimated Marginal Means

1. Time

Estimates

Measure: ERFD

Time	Mean	Std. Error	99% Confidence Interval	
			Lower Bound	Upper Bound
1	3640.408	403.258	2486.714	4794.103
2	3496.002	393.273	2370.874	4621.129
3	3880.876	566.645	2259.743	5502.009
4	3534.489	375.303	2460.772	4608.207
5	3546.770	445.242	2272.963	4820.577

Pairwise Comparisons

Measure: ERFD

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	99% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	144.407	71.347	.573	-132.663	421.477
	3	-240.468	236.336	1.000	-1158.258	677.322
	4	105.919	71.913	1.000	-173.350	385.188
	5	93.638	89.082	1.000	-252.305	439.582
2	1	-144.407	71.347	.573	-421.477	132.663
	3	-384.875	230.529	1.000	-1280.113	510.364
	4	-38.488	82.761	1.000	-359.883	282.908
	5	-50.768	85.048	1.000	-381.043	279.507
3	1	240.468	236.336	1.000	-677.322	1158.258
	2	384.875	230.529	1.000	-510.364	1280.113
	4	346.387	280.883	1.000	-744.396	1437.170
	5	334.106	200.083	1.000	-442.899	1111.111
4	1	-105.919	71.913	1.000	-385.188	173.350
	2	38.488	82.761	1.000	-282.908	359.883
	3	-346.387	280.883	1.000	-1437.170	744.396
	5	-12.281	120.683	1.000	-480.943	456.382
5	1	-93.638	89.082	1.000	-439.582	252.305
	2	50.768	85.048	1.000	-279.507	381.043
	3	-334.106	200.083	1.000	-1111.111	442.899
	4	12.281	120.683	1.000	-456.382	480.943

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.290	1.634[a]	4.000	16.000	.214	.290	6.536	.159
Wilks' lambda	.710	1.634[a]	4.000	16.000	.214	.290	6.536	.159
Hotelling's trace	.409	1.634[a]	4.000	16.000	.214	.290	6.536	.159
Roy's largest root	.409	1.634[a]	4.000	16.000	.214	.290	6.536	.159

Each F tests the multivariate effect of Time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .01

2. Condition

Estimates

Measure: ERFD

			99% Confidence Interval	
Condition	Mean	Std. Error	Lower Bound	Upper Bound
1	3678.626	469.953	2334.121	5023.132
2	3560.792	400.485	2415.032	4706.552

Pairwise Comparisons

Measure: ERFD

		Mean Difference			99% Confidence Interval for Difference[a]	
(I) Condition	(J) Condition	(I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	117.834	156.473	.461	-329.825	565.494
2	1	-117.834	156.473	.461	-565.494	329.825

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.029	.567[a]	1.000	19.000	.461	.029	.567	.030
Wilks' lambda	.971	.567[a]	1.000	19.000	.461	.029	.567	.030
Hotelling's trace	.030	.567[a]	1.000	19.000	.461	.029	.567	.030
Roy's largest root	.030	.567[a]	1.000	19.000	.461	.029	.567	.030

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

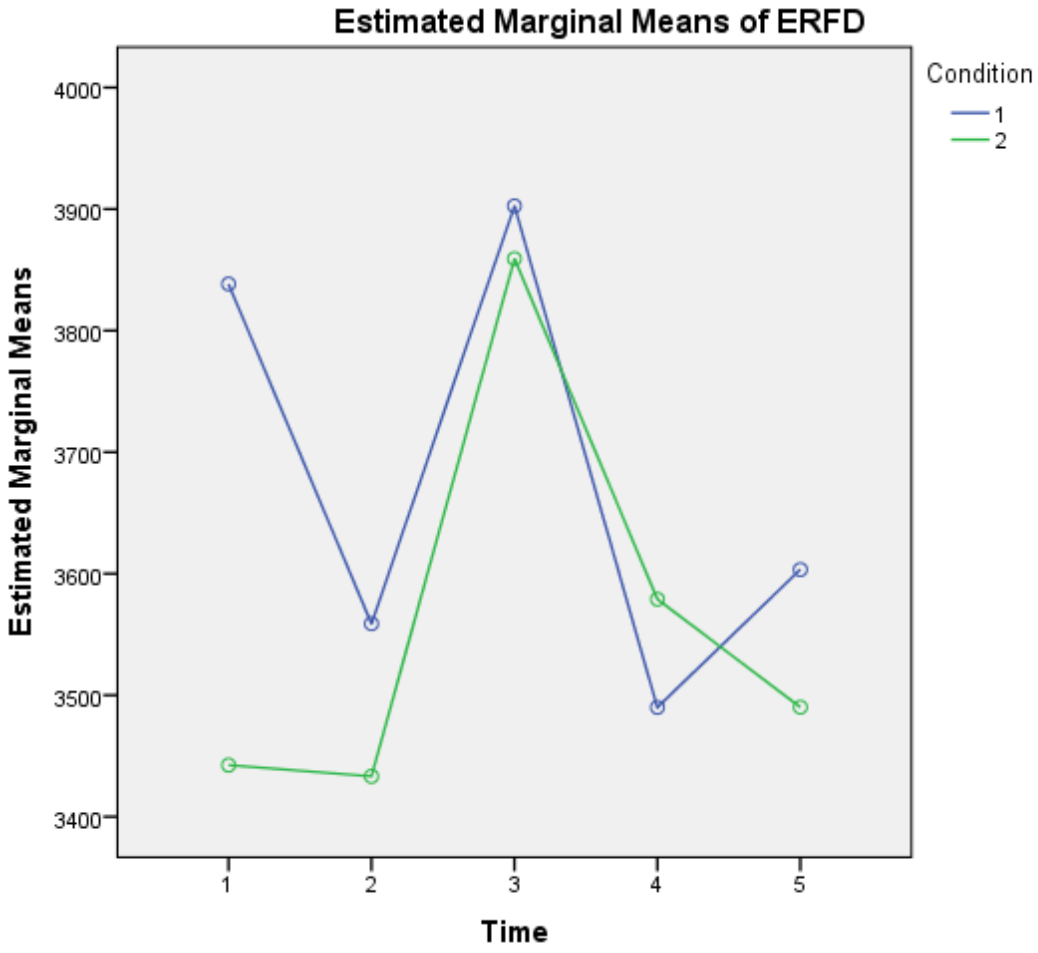
b. Computed using alpha = .01

3. Condition * Time

Measure: ERFD

				99% Confidence Interval	
Condition	Time	Mean	Std. Error	Lower Bound	Upper Bound
1	1	3838.345	444.844	2565.676	5111.014
	2	3558.782	390.782	2440.781	4676.783
	3	3902.611	690.389	1927.452	5877.769
	4	3489.978	416.305	2298.957	4680.999
	5	3603.417	488.651	2205.419	5001.414
2	1	3442.472	383.187	2346.198	4538.746
	2	3433.221	418.708	2235.324	4631.119
	3	3859.142	482.464	2478.843	5239.441
	4	3579.001	371.332	2516.644	4641.358
	5	3490.123	409.625	2318.212	4662.035

Profile Plots



General Linear Model

Within-Subjects Factors

Measure: MRFD

Condition	Time	Dependent Variable
1	1	Pre_Cont
	2	Post1_Cont
	3	Post5_Cont
	4	Post10_Cont
	5	Post15_Cont
2	1	Pre_Exp
	2	Post1_Exp
	3	Post5_Exp
	4	Post10_Exp
	5	Post15_Exp

Descriptive Statistics

	Mean	Std. Deviation	N
Pre_Cont	3500.32	1951.343	22
Post1_Cont	3276.33	1836.611	22
Post5_Cont	3624.43	2825.330	22
Post10_Cont	3091.11	1775.485	22
Post15_Cont	3307.63	2036.531	22
Pre_Exp	3206.16	1677.405	22
Post1_Exp	3079.49	1778.641	22
Post5_Exp	3150.24	1961.264	22
Post10_Exp	3324.90	1658.578	22
Post15_Exp	3219.70	1885.981	22

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Condition	Pillai's Trace	.055	1.221[b]	1.000	21.000	.282	.055	1.221	.060
	Wilks' Lambda	.945	1.221[b]	1.000	21.000	.282	.055	1.221	.060
	Hotelling's Trace	.058	1.221[b]	1.000	21.000	.282	.055	1.221	.060
	Roy's Largest Root	.058	1.221[b]	1.000	21.000	.282	.055	1.221	.060
Time	Pillai's Trace	.266	1.631[b]	4.000	18.000	.210	.266	6.522	.168
	Wilks' Lambda	.734	1.631[b]	4.000	18.000	.210	.266	6.522	.168
	Hotelling's Trace	.362	1.631[b]	4.000	18.000	.210	.266	6.522	.168
	Roy's Largest Root	.362	1.631[b]	4.000	18.000	.210	.266	6.522	.168
Condition * Time	Pillai's Trace	.323	2.143[b]	4.000	18.000	.117	.323	8.574	.247
	Wilks' Lambda	.677	2.143[b]	4.000	18.000	.117	.323	8.574	.247
	Hotelling's Trace	.476	2.143[b]	4.000	18.000	.117	.323	8.574	.247
	Roy's Largest Root	.476	2.143[b]	4.000	18.000	.117	.323	8.574	.247

a. Design: Intercept

Within Subjects Design: Condition + Time + Condition * Time

b. Exact statistic

c. Computed using alpha = .01

Mauchly's Test of Sphericity[a]

Measure: MRFD

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse -Geisser	Huynh-Feldt	Lower-bound
Condition	1.000	.000	0	.	1.000	1.000	1.000
Time	.080	49.082	9	.000	.504	.558	.250
Condition * Time	.491	13.793	9	.131	.706	.827	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Condition + Time + Condition * Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: MRFD

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	1476894.435	1	1476894.435	1.221	.282	.055	1.221	.060
	Greenhouse-Geisser	1476894.435	1.000	1476894.435	1.221	.282	.055	1.221	.060
	Huynh-Feldt	1476894.435	1.000	1476894.435	1.221	.282	.055	1.221	.060
	Lower-bound	1476894.435	1.000	1476894.435	1.221	.282	.055	1.221	.060
Error(Condition)	Sphericity Assumed	25398435.422	21	1209449.306					
	Greenhouse-Geisser	25398435.422	21.000	1209449.306					
	Huynh-Feldt	25398435.422	21.000	1209449.306					
	Lower-bound	25398435.422	21.000	1209449.306					
Time	Sphericity Assumed	1440469.150	4	360117.287	.675	.611	.031	2.701	.074
	Greenhouse-Geisser	1440469.150	2.016	714476.633	.675	.516	.031	1.362	.049
	Huynh-Feldt	1440469.150	2.231	645637.075	.675	.529	.031	1.507	.052
	Lower-bound	1440469.150	1.000	1440469.150	.675	.420	.031	.675	.035
Error(Time)	Sphericity Assumed	44791661.247	84	533234.062					
	Greenhouse-Geisser	44791661.247	42.338	1057942.206					
	Huynh-Feldt	44791661.247	46.853	956009.867					
	Lower-bound	44791661.247	21.000	2132936.250					
Condition * Time	Sphericity Assumed	3060886.161	4	765221.540	1.809	.135	.079	7.236	.287
	Greenhouse-Geisser	3060886.161	2.825	1083609.049	1.809	.158	.079	5.110	.209
	Huynh-Feldt	3060886.161	3.309	924992.360	1.809	.148	.079	5.986	.241
	Lower-bound	3060886.161	1.000	3060886.161	1.809	.193	.079	1.809	.091
Error(Condition* Time)	Sphericity Assumed	35533024.071	84	423012.191					
	Greenhouse-Geisser	35533024.071	59.319	599015.859					
	Huynh-Feldt	35533024.071	69.491	511333.025					
	Lower-bound	35533024.071	21.000	1692048.765					

a. Computed using alpha = .01

Tests of Within-Subjects Contrasts

Measure: MRFD

Source	Condition	Time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Linear		1476894.435	1	1476894.435	1.221	.282	.055	1.221	.060
Error(Condition)	Linear		25398435.422	21	1209449.306					
Time		Linear	97768.722	1	97768.722	.794	.383	.036	.794	.040
		Quadratic	16853.518	1	16853.518	.037	.850	.002	.037	.011
		Cubic	98682.315	1	98682.315	.258	.617	.012	.258	.019
		Order 4	1227164.594	1	1227164.594	1.049	.317	.048	1.049	.052
Error(Time)		Linear	2586660.535	21	123174.311					
		Quadratic	9600509.417	21	457167.115					
		Cubic	8029692.982	21	382366.332					
		Order 4	24574798.314	21	1170228.491					
Condition * Time	Linear	Linear	781905.357	1	781905.357	3.121	.092	.129	3.121	.172
		Quadratic	17037.088	1	17037.088	.059	.810	.003	.059	.012
		Cubic	471966.277	1	471966.277	1.295	.268	.058	1.295	.064
		Order 4	1789977.439	1	1789977.439	2.270	.147	.098	2.270	.118
Error(Condition* Time)	Linear	Linear	5260518.750	21	250500.893					
		Quadratic	6058011.767	21	288476.751					
		Cubic	7653164.959	21	364436.427					
		Order 4	16561328.595	21	788634.695					

a. Computed using alpha = .01

Tests of Between-Subjects Effects

Measure: MRFD

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	2364006248.059	1	2364006248.059	70.440	.000	.770	70.440	1.000
Error	704767378.585	21	33560351.361					

a. Computed using alpha = .01

Estimated Marginal Means

1. Condition

Estimates

Measure: MRFD

Condition	Mean	Std. Error	99% Confidence Interval	
			Lower Bound	Upper Bound
1	3359.964	424.716	2157.441	4562.488
2	3196.096	368.382	2153.074	4239.119

Pairwise Comparisons

Measure: MRFD

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	99% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	163.868	148.290	.282	-255.995	583.731
2	1	-163.868	148.290	.282	-583.731	255.995

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.055	1.221[a]	1.000	21.000	.282	.055	1.221	.060
Wilks' lambda	.945	1.221[a]	1.000	21.000	.282	.055	1.221	.060
Hotelling's trace	.058	1.221[a]	1.000	21.000	.282	.055	1.221	.060
Roy's largest root	.058	1.221[a]	1.000	21.000	.282	.055	1.221	.060

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .01

2. Time

Estimates

Measure: MRFD

Time	Mean	Std. Error	99% Confidence Interval	
			Lower Bound	Upper Bound
1	3353.241	376.099	2288.370	4418.112
2	3177.911	363.956	2147.423	4208.400
3	3387.333	497.139	1979.754	4794.913
4	3208.002	344.631	2232.229	4183.776
5	3263.664	413.980	2091.537	4435.790

Pairwise Comparisons

Measure: MRFD

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	99% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	175.330	67.014	.161	-80.617	431.276
	3	-34.092	190.240	1.000	-760.671	692.487
	4	145.239	105.787	1.000	-258.793	549.270
	5	89.578	102.648	1.000	-302.464	481.619
2	1	-175.330	67.014	.161	-431.276	80.617
	3	-209.422	205.588	1.000	-994.621	575.777
	4	-30.091	111.546	1.000	-456.115	395.934
	5	-85.752	87.205	1.000	-418.813	247.308
3	1	34.092	190.240	1.000	-692.487	760.671
	2	209.422	205.588	1.000	-575.777	994.621
	4	179.331	231.722	1.000	-705.681	1064.343
	5	123.670	190.678	1.000	-604.582	851.922
4	1	-145.239	105.787	1.000	-549.270	258.793
	2	30.091	111.546	1.000	-395.934	456.115
	3	-179.331	231.722	1.000	-1064.343	705.681
	5	-55.661	166.139	1.000	-690.193	578.870
5	1	-89.578	102.648	1.000	-481.619	302.464
	2	85.752	87.205	1.000	-247.308	418.813
	3	-123.670	190.678	1.000	-851.922	604.582
	4	55.661	166.139	1.000	-578.870	690.193

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.266	1.631[a]	4.000	18.000	.210	.266	6.522	.168
Wilks' lambda	.734	1.631[a]	4.000	18.000	.210	.266	6.522	.168
Hotelling's trace	.362	1.631[a]	4.000	18.000	.210	.266	6.522	.168
Roy's largest root	.362	1.631[a]	4.000	18.000	.210	.266	6.522	.168

Each F tests the multivariate effect of Time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

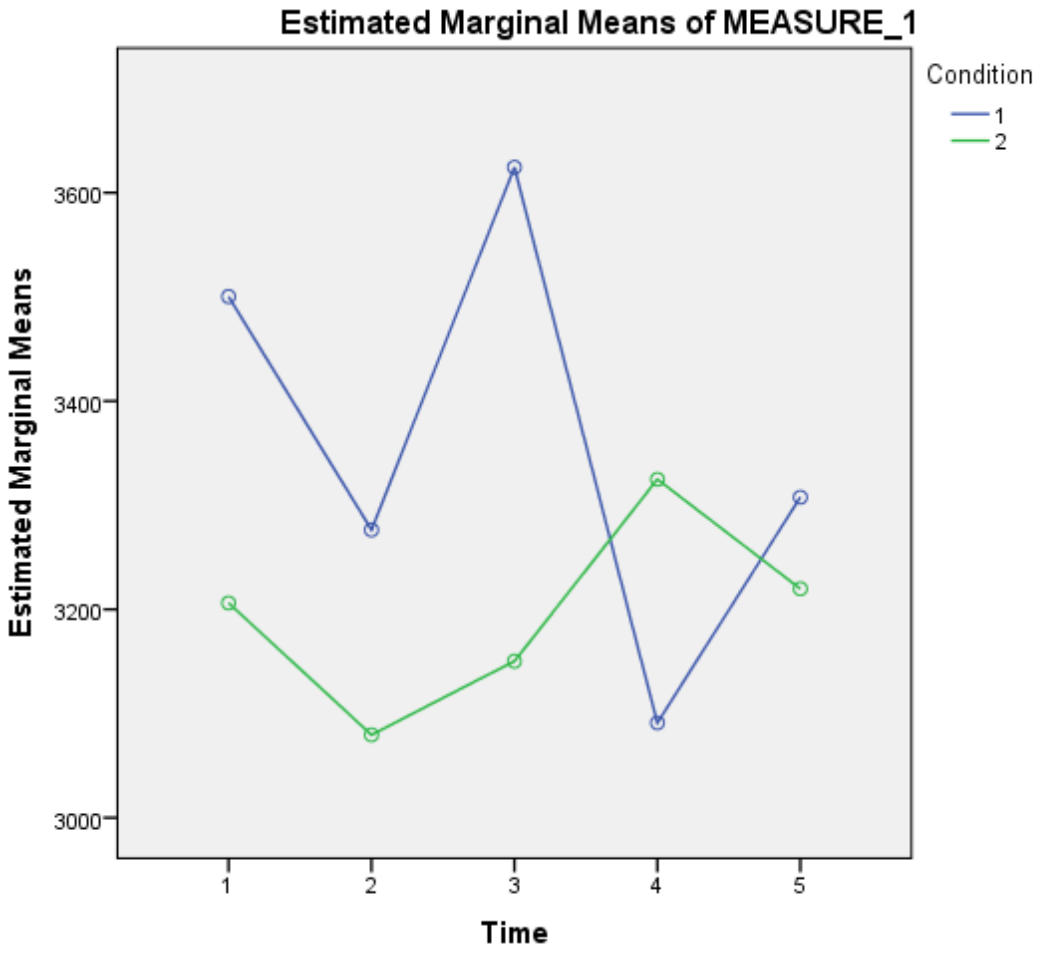
b. Computed using alpha = .01

3. Condition * Time

Measure: MRFD

				99% Confidence Interval	
Condition	Time	Mean	Std. Error	Lower Bound	Upper Bound
1	1	3500.323	416.028	2322.399	4678.247
	2	3276.333	391.567	2167.667	4384.999
	3	3624.429	602.362	1918.924	5329.934
	4	3091.108	378.535	2019.340	4162.876
	5	3307.628	434.190	2078.280	4536.975
2	1	3206.159	357.624	2193.597	4218.721
	2	3079.490	379.208	2005.817	4153.163
	3	3150.238	418.143	1966.325	4334.151
	4	3324.896	353.610	2323.700	4326.093
	5	3219.700	402.092	2081.231	4358.168

Profile Plots



General Linear Model

Within-Subjects Factors

Measure: PRFD

Condition	Time	Dependent Variable
1	1	Pre_Cont
	2	Post1_Cont
	3	Post5_Cont
	4	Post10_Cont
	5	Post15_Cont
2	1	Pre_Exp
	2	Post1_Exp
	3	Post5_Exp
	4	Post10_Exp
	5	Post15_Exp

Descriptive Statistics

	Mean	Std. Deviation	N
Pre_Cont	8590.5600	4034.20142	21
Post1_Cont	8197.2862	4061.79552	21
Post5_Cont	10065.3343	12147.84672	21
Post10_Cont	7865.4648	4355.92636	21
Post15_Cont	8098.9690	5957.51298	21
Pre_Exp	9565.5490	6855.26617	21
Post1_Exp	7877.7543	4343.67715	21
Post5_Exp	8098.9681	4377.17536	21
Post10_Exp	7337.0019	2969.18507	21
Post15_Exp	8234.1586	4904.23649	21

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Condition	Pillai's Trace	.017	.355[b]	1.000	20.000	.558	.017	.355	.022
	Wilks' Lambda	.983	.355[b]	1.000	20.000	.558	.017	.355	.022
	Hotelling's Trace	.018	.355[b]	1.000	20.000	.558	.017	.355	.022
	Roy's Largest Root	.018	.355[b]	1.000	20.000	.558	.017	.355	.022
Time	Pillai's Trace	.180	.931[b]	4.000	17.000	.470	.180	3.722	.078
	Wilks' Lambda	.820	.931[b]	4.000	17.000	.470	.180	3.722	.078
	Hotelling's Trace	.219	.931[b]	4.000	17.000	.470	.180	3.722	.078
	Roy's Largest Root	.219	.931[b]	4.000	17.000	.470	.180	3.722	.078
Condition * Time	Pillai's Trace	.122	.591[b]	4.000	17.000	.674	.122	2.365	.046
	Wilks' Lambda	.878	.591[b]	4.000	17.000	.674	.122	2.365	.046
	Hotelling's Trace	.139	.591[b]	4.000	17.000	.674	.122	2.365	.046
	Roy's Largest Root	.139	.591[b]	4.000	17.000	.674	.122	2.365	.046

a. Design: Intercept

Within Subjects Design: Condition + Time + Condition * Time

b. Exact statistic

c. Computed using alpha = .01

Mauchly's Test of Sphericity[a]

Measure: PRFD

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	1.000	.000	0	.	1.000	1.000	1.000
Time	.065	50.449	9	.000	.489	.542	.250
Condition * Time	.045	57.233	9	.000	.494	.548	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Condition + Time + Condition * Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: PRFD

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	6098898.934	1	6098898.934	.355	.558	.017	.355	.022
	Greenhouse-Geisser	6098898.934	1.000	6098898.934	.355	.558	.017	.355	.022
	Huynh-Feldt	6098898.934	1.000	6098898.934	.355	.558	.017	.355	.022
	Lower-bound	6098898.934	1.000	6098898.934	.355	.558	.017	.355	.022
Error(Condition)	Sphericity Assumed	343806418.146	20	17190320.907					
	Greenhouse-Geisser	343806418.146	20.000	17190320.907					
	Huynh-Feldt	343806418.146	20.000	17190320.907					
	Lower-bound	343806418.146	20.000	17190320.907					
Time	Sphericity Assumed	73448029.532	4	18362007.383	.994	.416	.047	3.977	.123
	Greenhouse-Geisser	73448029.532	1.957	37539253.778	.994	.378	.047	1.945	.072
	Huynh-Feldt	73448029.532	2.166	33904484.705	.994	.384	.047	2.154	.077
	Lower-bound	73448029.532	1.000	73448029.532	.994	.331	.047	.994	.049
Error(Time)	Sphericity Assumed	1477623156.358	80	18470289.454					
	Greenhouse-Geisser	1477623156.358	39.131	37760625.444					
	Huynh-Feldt	1477623156.358	43.326	34104421.877					
	Lower-bound	1477623156.358	20.000	73881157.818					
Condition * Time	Sphericity Assumed	48678020.553	4	12169505.138	.667	.617	.032	2.667	.073
	Greenhouse-Geisser	48678020.553	1.977	24625213.470	.667	.517	.032	1.318	.047
	Huynh-Feldt	48678020.553	2.192	22204367.536	.667	.532	.032	1.462	.050
	Lower-bound	48678020.553	1.000	48678020.553	.667	.424	.032	.667	.034
Error(Condition* Time)	Sphericity Assumed	1460314808.618	80	18253935.108					
	Greenhouse-Geisser	1460314808.618	39.535	36937167.419					
	Huynh-Feldt	1460314808.618	43.845	33305962.691					
	Lower-bound	1460314808.618	20.000	73015740.431					

a. Computed using alpha = .01

Tests of Within-Subjects Contrasts

Measure: PRFD

Source	Condition	Time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Linear		6098898.934	1	6098898.934	.355	.558	.017	.355	.022
Error(Condition)	Linear		343806418.146	20	17190320.907					
Time		Linear	21438030.481	1	21438030.481	1.996	.173	.091	1.996	.101
		Quadratic	1412531.526	1	1412531.526	.078	.783	.004	.078	.013
		Cubic	6360.991	1	6360.991	.001	.977	.000	.001	.010
		Order 4	50591106.533	1	50591106.533	1.336	.261	.063	1.336	.065
Error(Time)		Linear	214782010.690	20	10739100.535					
		Quadratic	361592975.084	20	18079648.754					
		Cubic	144039126.547	20	7201956.327					
		Order 4	757209044.037	20	37860452.202					
Condition * Time	Linear	Linear	3744872.839	1	3744872.839	.299	.591	.015	.299	.020
		Quadratic	36761385.882	1	36761385.882	2.015	.171	.092	2.015	.102
		Cubic	186932.922	1	186932.922	.040	.843	.002	.040	.011
		Order 4	7984828.910	1	7984828.910	.212	.650	.011	.212	.017
Error(Condition* Time)	Linear	Linear	250814537.917	20	12540726.896					
		Quadratic	364844761.210	20	18242238.060					
		Cubic	92614866.276	20	4630743.314					
		Order 4	752040643.216	20	37602032.161					

a. Computed using alpha = .01

Tests of Between-Subjects Effects

Measure: PRFD

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	14793283047.146	1	14793283047.146	78.433	.000	.797	78.433	1.000
Error	3772228904.456	20	188611445.223					

a. Computed using alpha = .01

Estimated Marginal Means
1. Condition

Estimates

Measure: PRFD

Condition	Mean	Std. Error	99% Confidence Interval	
			Lower Bound	Upper Bound
1	8563.523	1135.720	5332.014	11795.031
2	8222.686	818.631	5893.402	10551.971

Pairwise Comparisons

Measure: PRFD

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	99% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	340.836	572.219	.558	-1287.321	1968.994
2	1	-340.836	572.219	.558	-1968.994	1287.321

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.017	.355[a]	1.000	20.000	.558	.017	.355	.022
Wilks' lambda	.983	.355[a]	1.000	20.000	.558	.017	.355	.022
Hotelling's trace	.018	.355[a]	1.000	20.000	.558	.017	.355	.022
Roy's largest root	.018	.355[a]	1.000	20.000	.558	.017	.355	.022

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .01

2. Time

Estimates

Measure: PRFD

Time	Mean	Std. Error	99% Confidence Interval	
			Lower Bound	Upper Bound
1	9078.054	975.609	6302.116	11853.993
2	8037.520	817.310	5711.997	10363.044
3	9082.151	1669.963	4330.540	13833.762
4	7601.233	757.007	5447.291	9755.176
5	8166.564	1126.136	4962.325	11370.802

Pairwise Comparisons

Measure: PRFD

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	99% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	1040.534	751.209	1.000	-1851.258	3932.326
	3	-4.097	1363.325	1.000	-5252.239	5244.046
	4	1476.821	756.799	.652	-1436.488	4390.130
	5	911.491	842.556	1.000	-2331.944	4154.925
2	1	-1040.534	751.209	1.000	-3932.326	1851.258
	3	-1044.631	1115.373	1.000	-5338.277	3249.015
	4	436.287	380.046	1.000	-1026.705	1899.279
	5	-129.044	516.401	1.000	-2116.939	1858.852
3	1	4.097	1363.325	1.000	-5244.046	5252.239
	2	1044.631	1115.373	1.000	-3249.015	5338.277
	4	1480.918	1384.706	1.000	-3849.529	6811.365
	5	915.587	1014.166	1.000	-2988.461	4819.636
4	1	-1476.821	756.799	.652	-4390.130	1436.488
	2	-436.287	380.046	1.000	-1899.279	1026.705
	3	-1480.918	1384.706	1.000	-6811.365	3849.529
	5	-565.330	699.039	1.000	-3256.292	2125.631
5	1	-911.491	842.556	1.000	-4154.925	2331.944
	2	129.044	516.401	1.000	-1858.852	2116.939
	3	-915.587	1014.166	1.000	-4819.636	2988.461
	4	565.330	699.039	1.000	-2125.631	3256.292

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.180	.931[a]	4.000	17.000	.470	.180	3.722	.078
Wilks' lambda	.820	.931[a]	4.000	17.000	.470	.180	3.722	.078
Hotelling's trace	.219	.931[a]	4.000	17.000	.470	.180	3.722	.078
Roy's largest root	.219	.931[a]	4.000	17.000	.470	.180	3.722	.078

Each F tests the multivariate effect of Time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

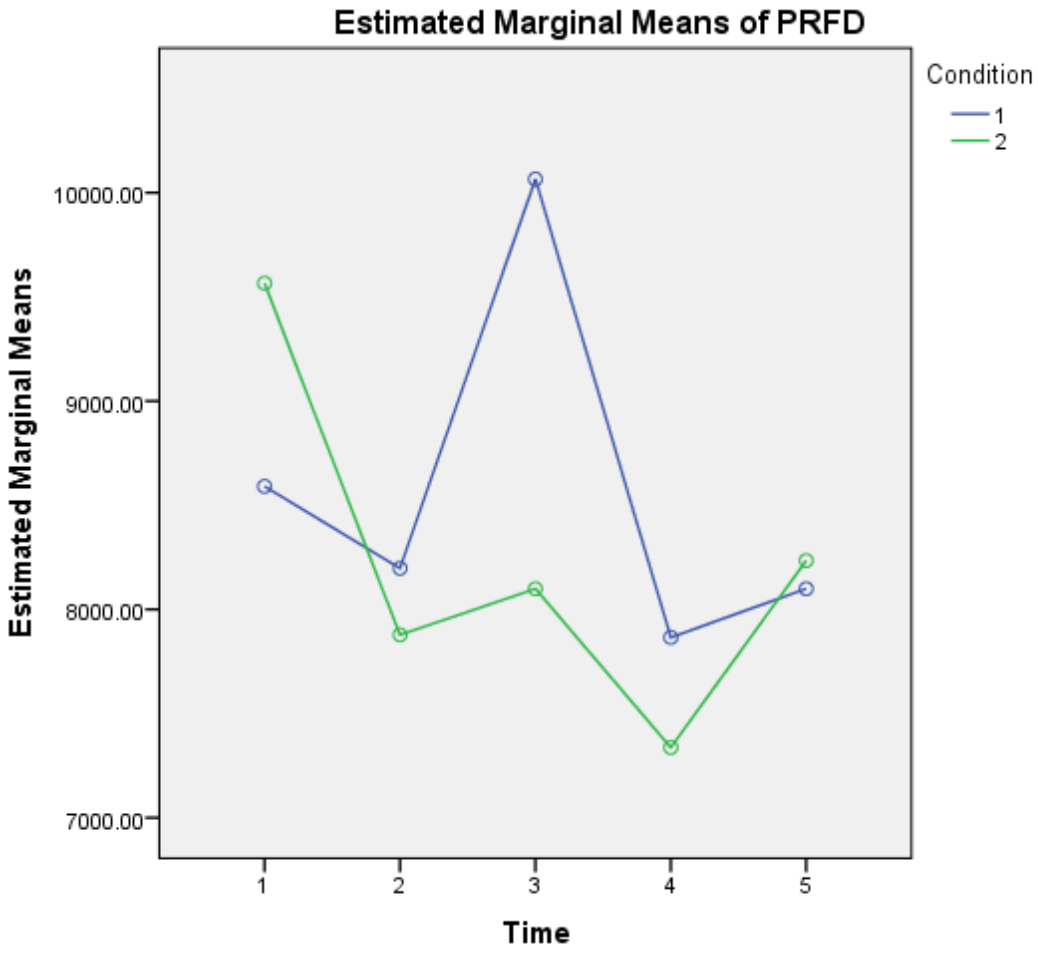
b. Computed using alpha = .01

3. Condition * Time

Measure: PRFD

Condition	Time	Mean	Std. Error	99% Confidence Interval	
				Lower Bound	Upper Bound
1	1	8590.560	880.335	6085.708	11095.412
	2	8197.286	886.356	5675.301	10719.271
	3	10065.334	2650.877	2522.687	17607.981
	4	7865.465	950.541	5160.853	10570.077
	5	8098.969	1300.036	4399.925	11798.013
2	1	9565.549	1495.942	5309.087	13822.011
	2	7877.754	947.868	5180.748	10574.761
	3	8098.968	955.178	5381.162	10816.774
	4	7337.002	647.929	5493.423	9180.581
	5	8234.159	1070.192	5189.098	11279.219

Profile Plots



General Linear Model

Within-Subjects Factors

Measure: RSI

Condition	Time	Dependent Variable
1	1	Pre_Cont
	2	Post1_Cont
	3	Post5_Cont
	4	Post10_Cont
	5	Post15_Cont
2	1	Pre_Exp
	2	Post1_Exp
	3	Post5_Exp
	4	Post10_Exp
	5	Post15_Exp

Descriptive Statistics

	Mean	Std. Deviation	N
Pre_Cont	.3658	.20670	19
Post1_Cont	.3232	.16269	19
Post5_Cont	.3331	.18749	19
Post10_Cont	.3026	.13144	19
Post15_Cont	.2932	.15745	19
Pre_Exp	.3168	.13853	19
Post1_Exp	.3147	.14210	19
Post5_Exp	.3205	.14285	19
Post10_Exp	.3205	.14623	19
Post15_Exp	.3295	.19696	19

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Condition	Pillai's Trace	.008	.148[b]	1.000	18.000	.705	.008	.148	.015
	Wilks' Lambda	.992	.148[b]	1.000	18.000	.705	.008	.148	.015
	Hotelling's Trace	.008	.148[b]	1.000	18.000	.705	.008	.148	.015
	Roy's Largest Root	.008	.148[b]	1.000	18.000	.705	.008	.148	.015
Time	Pillai's Trace	.463	3.238[b]	4.000	15.000	.042	.463	12.953	.392
	Wilks' Lambda	.537	3.238[b]	4.000	15.000	.042	.463	12.953	.392
	Hotelling's Trace	.864	3.238[b]	4.000	15.000	.042	.463	12.953	.392
	Roy's Largest Root	.864	3.238[b]	4.000	15.000	.042	.463	12.953	.392
Condition * Time	Pillai's Trace	.379	2.284[b]	4.000	15.000	.108	.379	9.137	.245
	Wilks' Lambda	.621	2.284[b]	4.000	15.000	.108	.379	9.137	.245
	Hotelling's Trace	.609	2.284[b]	4.000	15.000	.108	.379	9.137	.245
	Roy's Largest Root	.609	2.284[b]	4.000	15.000	.108	.379	9.137	.245

a. Design: Intercept

Within Subjects Design: Condition + Time + Condition * Time

b. Exact statistic

c. Computed using alpha = .01

Mauchly's Test of Sphericity[a]

Measure: RSI

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	1.000	.000	0	.	1.000	1.000	1.000
Time	.145	31.655	9	.000	.560	.644	.250
Condition * Time	.215	25.211	9	.003	.581	.672	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Condition + Time + Condition * Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: RSI

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	.000	1	.000	.148	.705	.008	.148	.015
	Greenhouse-Geisser	.000	1.000	.000	.148	.705	.008	.148	.015
	Huynh-Feldt	.000	1.000	.000	.148	.705	.008	.148	.015
	Lower-bound	.000	1.000	.000	.148	.705	.008	.148	.015
Error(Condition)	Sphericity Assumed	.057	18	.003					
	Greenhouse-Geisser	.057	18.000	.003					
	Huynh-Feldt	.057	18.000	.003					
	Lower-bound	.057	18.000	.003					
Time	Sphericity Assumed	.024	4	.006	2.073	.093	.103	8.294	.340
	Greenhouse-Geisser	.024	2.241	.011	2.073	.134	.103	4.646	.200
	Huynh-Feldt	.024	2.574	.009	2.073	.125	.103	5.338	.226
	Lower-bound	.024	1.000	.024	2.073	.167	.103	2.073	.103
Error(Time)	Sphericity Assumed	.207	72	.003					
	Greenhouse-Geisser	.207	40.330	.005					
	Huynh-Feldt	.207	46.339	.004					
	Lower-bound	.207	18.000	.012					
Condition * Time	Sphericity Assumed	.040	4	.010	3.683	.009	.170	14.730	.669
	Greenhouse-Geisser	.040	2.324	.017	3.683	.028	.170	8.557	.434
	Huynh-Feldt	.040	2.689	.015	3.683	.022	.170	9.901	.492
	Lower-bound	.040	1.000	.040	3.683	.071	.170	3.683	.203
Error(Condition* Time)	Sphericity Assumed	.196	72	.003					
	Greenhouse-Geisser	.196	41.825	.005					
	Huynh-Feldt	.196	48.396	.004					
	Lower-bound	.196	18.000	.011					

a. Computed using alpha = .01

Tests of Within-Subjects Contrasts

Measure: RSI

Source	Condition	Time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Linear		.000	1	.000	.148	.705	.008	.148	.015
Error(Condition)	Linear		.057	18	.003					
Time		Linear	.017	1	.017	6.260	.022	.258	6.260	.381
		Quadratic	.001	1	.001	.525	.478	.028	.525	.028
		Cubic	.001	1	.001	.197	.662	.011	.197	.016
		Order 4	.005	1	.005	2.301	.147	.113	2.301	.116
Error(Time)		Linear	.050	18	.003					
		Quadratic	.041	18	.002					
		Cubic	.081	18	.004					
		Order 4	.035	18	.002					
Condition * Time	Linear	Linear	.037	1	.037	7.184	.015	.285	7.184	.444
		Quadratic	6.226E-5	1	6.23E-5	.019	.892	.001	.019	.011
		Cubic	.001	1	.001	1.107	.307	.058	1.107	.053
		Order 4	.002	1	.002	1.413	.250	.073	1.413	.068
Error(Condition* Time)	Linear	Linear	.092	18	.005					
		Quadratic	.060	18	.003					
		Cubic	.016	18	.001					
		Order 4	.027	18	.002					

a. Computed using alpha = .01

Tests of Between-Subjects Effects

Measure: RSI

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	19.699	1	19.699	81.807	.000	.820	81.807	1.000
Error	4.334	18	.241					

a. Computed using alpha = .01

Estimated Marginal Means
1. Condition

Estimates

Measure: RSI

Condition	Mean	Std. Error	99% Confidence Interval	
			Lower Bound	Upper Bound
1	.324	.037	.217	.430
2	.320	.034	.221	.420

Pairwise Comparisons

Measure: RSI

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	99% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.003	.008	.705	-.020	.027
2	1	-.003	.008	.705	-.027	.020

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.008	.148[a]	1.000	18.000	.705	.008	.148	.015
Wilks' lambda	.992	.148[a]	1.000	18.000	.705	.008	.148	.015
Hotelling's trace	.008	.148[a]	1.000	18.000	.705	.008	.148	.015
Roy's largest root	.008	.148[a]	1.000	18.000	.705	.008	.148	.015

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .01

2. Time

Estimates

Measure: RSI

Time	Mean	Std. Error	99% Confidence Interval	
			Lower Bound	Upper Bound
1	.341	.038	.231	.451
2	.319	.034	.220	.418
3	.327	.037	.220	.434
4	.312	.031	.222	.402
5	.311	.040	.195	.428

Pairwise Comparisons

Measure: RSI

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	99% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	.022	.015	1.000	-.038	.083
	3	.015	.014	1.000	-.039	.068
	4	.030	.011	.131	-.013	.072
	5	.030	.017	.931	-.036	.096
2	1	-.022	.015	1.000	-.083	.038
	3	-.008	.007	1.000	-.036	.020
	4	.007	.010	1.000	-.031	.046
	5	.008	.010	1.000	-.031	.046
3	1	-.015	.014	1.000	-.068	.039
	2	.008	.007	1.000	-.020	.036
	4	.015	.011	1.000	-.029	.060
	5	.016	.009	1.000	-.021	.052
4	1	-.030	.011	.131	-.072	.013
	2	-.007	.010	1.000	-.046	.031
	3	-.015	.011	1.000	-.060	.029
	5	.000	.015	1.000	-.060	.060
5	1	-.030	.017	.931	-.096	.036
	2	-.008	.010	1.000	-.046	.031
	3	-.016	.009	1.000	-.052	.021
	4	.000	.015	1.000	-.060	.060

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.463	3.238[a]	4.000	15.000	.042	.463	12.953	.392
Wilks' lambda	.537	3.238[a]	4.000	15.000	.042	.463	12.953	.392
Hotelling's trace	.864	3.238[a]	4.000	15.000	.042	.463	12.953	.392
Roy's largest root	.864	3.238[a]	4.000	15.000	.042	.463	12.953	.392

Each F tests the multivariate effect of Time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

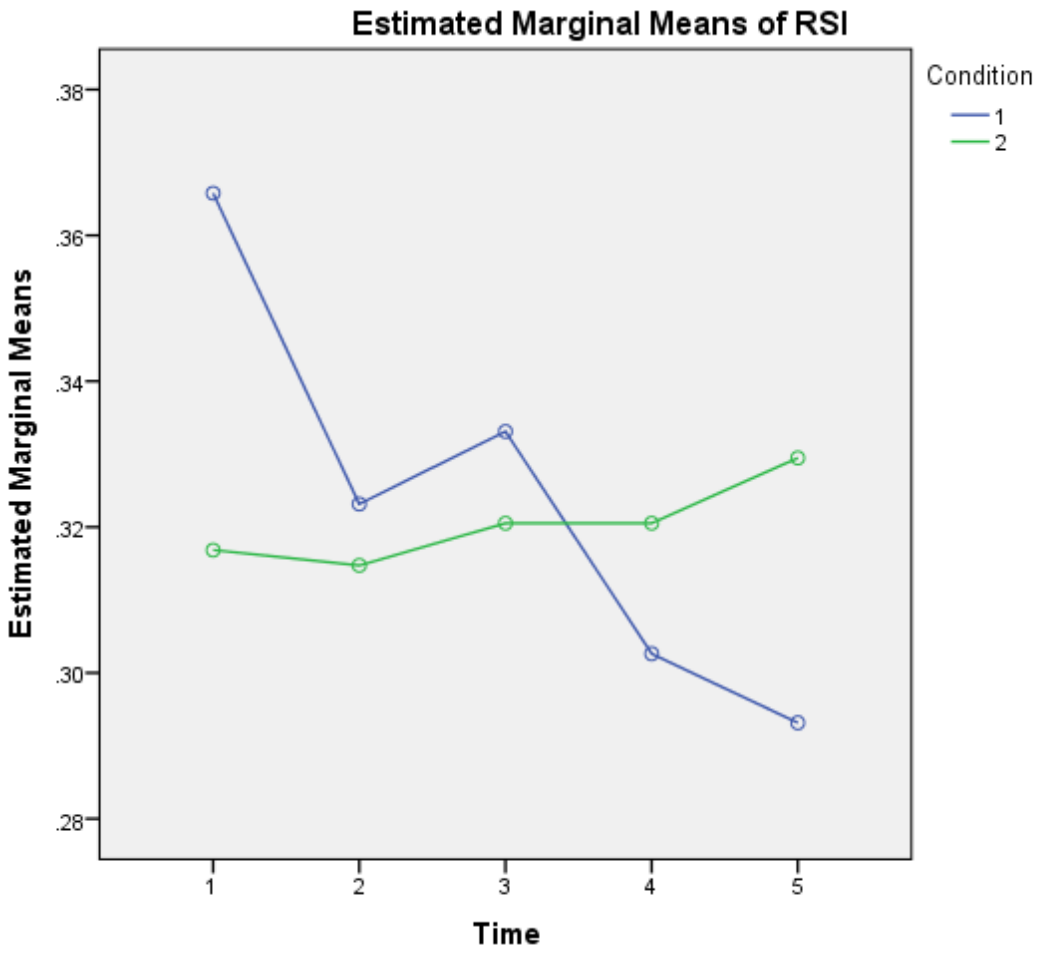
b. Computed using alpha = .01

3. Condition * Time

Measure: RSI

				99% Confidence Interval	
Condition	Time	Mean	Std. Error	Lower Bound	Upper Bound
1	1	.366	.047	.229	.502
	2	.323	.037	.216	.431
	3	.333	.043	.209	.457
	4	.303	.030	.216	.389
	5	.293	.036	.189	.397
2	1	.317	.032	.225	.408
	2	.315	.033	.221	.409
	3	.321	.033	.226	.415
	4	.321	.034	.224	.417
	5	.329	.045	.199	.460

Profile Plots



General Linear Model

Within-Subjects Factors

Measure: PP

Condition	Time	Dependent Variable
1	1	Pre_Cont
	2	Post1_Cont
	3	Post5_Cont
	4	Post10_Cont
	5	Post15_Cont
2	1	Pre_Exp
	2	Post1_Exp
	3	Post5_Exp
	4	Post10_Exp
	5	Post15_Exp

Descriptive Statistics

	Mean	Std. Deviation	N
Pre_Cont	3555.6467	1357.01095	21
Post1_Cont	3445.6833	1342.38119	21
Post5_Cont	3542.4286	1545.30190	21
Post10_Cont	3400.8662	1311.29613	21
Post15_Cont	3437.8252	1430.61494	21
Pre_Exp	3568.8524	1291.29039	21
Post1_Exp	3479.2000	1274.98023	21
Post5_Exp	3567.8081	1327.84058	21
Post10_Exp	3436.9648	1333.88857	21
Post15_Exp	3357.8343	1283.64525	21

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Condition	Pillai's Trace	.000	.007[b]	1.000	20.000	.933	.000	.007	.010
	Wilks' Lambda	1.000	.007[b]	1.000	20.000	.933	.000	.007	.010
	Hotelling's Trace	.000	.007[b]	1.000	20.000	.933	.000	.007	.010
	Roy's Largest Root	.000	.007[b]	1.000	20.000	.933	.000	.007	.010
Time	Pillai's Trace	.547	5.141[b]	4.000	17.000	.007	.547	20.566	.691
	Wilks' Lambda	.453	5.141[b]	4.000	17.000	.007	.547	20.566	.691
	Hotelling's Trace	1.210	5.141[b]	4.000	17.000	.007	.547	20.566	.691
	Roy's Largest Root	1.210	5.141[b]	4.000	17.000	.007	.547	20.566	.691
Condition * Time	Pillai's Trace	.363	2.420[b]	4.000	17.000	.089	.363	9.679	.284
	Wilks' Lambda	.637	2.420[b]	4.000	17.000	.089	.363	9.679	.284
	Hotelling's Trace	.569	2.420[b]	4.000	17.000	.089	.363	9.679	.284
	Roy's Largest Root	.569	2.420[b]	4.000	17.000	.089	.363	9.679	.284

a. Design: Intercept

Within Subjects Design: Condition + Time + Condition * Time

b. Exact statistic

c. Computed using alpha = .01

Mauchly's Test of Sphericity[a]

Measure: PP

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[b]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
Condition	1.000	.000	0	.	1.000	1.000	1.000
Time	.036	61.329	9	.000	.521	.583	.250
Condition * Time	.081	46.269	9	.000	.533	.598	.250

Tests the null hypothesis that the error covariance matrix of the orthonormalized transformed dependent variables is proportional to an identity matrix.

a. Design: Intercept

Within Subjects Design: Condition + Time + Condition * Time

b. May be used to adjust the degrees of freedom for the averaged tests of significance. Corrected tests are displayed in the Tests of Within-Subjects Effects table.

Tests of Within-Subjects Effects

Measure: PP

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Sphericity Assumed	1671.132	1	1671.132	.007	.933	.000	.007	.010
	Greenhouse-Geisser	1671.132	1.000	1671.132	.007	.933	.000	.007	.010
	Huynh-Feldt	1671.132	1.000	1671.132	.007	.933	.000	.007	.010
	Lower-bound	1671.132	1.000	1671.132	.007	.933	.000	.007	.010
Error(Condition)	Sphericity Assumed	4605163.348	20	230258.167					
	Greenhouse-Geisser	4605163.348	20.000	230258.167					
	Huynh-Feldt	4605163.348	20.000	230258.167					
	Lower-bound	4605163.348	20.000	230258.167					
Time	Sphericity Assumed	974271.328	4	243567.832	3.633	.009	.154	14.530	.666
	Greenhouse-Geisser	974271.328	2.085	467219.166	3.633	.033	.154	7.575	.394
	Huynh-Feldt	974271.328	2.333	417651.817	3.633	.028	.154	8.474	.434
	Lower-bound	974271.328	1.000	974271.328	3.633	.071	.154	3.633	.205
Error(Time)	Sphericity Assumed	5364136.052	80	67051.701					
	Greenhouse-Geisser	5364136.052	41.705	128620.596					
	Huynh-Feldt	5364136.052	46.655	114975.218					
	Lower-bound	5364136.052	20.000	268206.803					
Condition * Time	Sphericity Assumed	99586.010	4	24896.503	.383	.820	.019	1.532	.039
	Greenhouse-Geisser	99586.010	2.131	46733.003	.383	.697	.019	.816	.030
	Huynh-Feldt	99586.010	2.392	41625.798	.383	.721	.019	.916	.031
	Lower-bound	99586.010	1.000	99586.010	.383	.543	.019	.383	.023
Error(Condition* Time)	Sphericity Assumed	5200929.325	80	65011.617					
	Greenhouse-Geisser	5200929.325	42.619	122032.725					
	Huynh-Feldt	5200929.325	47.848	108696.407					
	Lower-bound	5200929.325	20.000	260046.466					

a. Computed using alpha = .01

Tests of Within-Subjects Contrasts

Measure: PP

Source	Condition	Time	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Condition	Linear		1671.132	1	1671.132	.007	.933	.000	.007	.010
Error(Condition)	Linear		4605163.348	20	230258.167					
Time		Linear	582356.146	1	582356.146	7.189	.014	.264	7.189	.454
		Quadratic	15308.980	1	15308.980	.916	.350	.044	.916	.045
		Cubic	25139.989	1	25139.989	1.224	.282	.058	1.224	.060
		Order 4	351466.214	1	351466.214	2.344	.141	.105	2.344	.121
Error(Time)		Linear	1620217.652	20	81010.883					
		Quadratic	334334.185	20	16716.709					
		Cubic	410908.423	20	20545.421					
		Order 4	2998675.791	20	149933.790					
Condition * Time	Linear	Linear	35475.973	1	35475.973	.639	.434	.031	.639	.033
		Quadratic	48365.957	1	48365.957	1.937	.179	.088	1.937	.098
		Cubic	10158.522	1	10158.522	.360	.556	.018	.360	.022
		Order 4	5585.558	1	5585.558	.037	.850	.002	.037	.011
Error(Condition* Time)	Linear	Linear	1110752.112	20	55537.606					
		Quadratic	499316.518	20	24965.826					
		Cubic	565146.553	20	28257.328					
		Order 4	3025714.141	20	151285.707					

a. Computed using alpha = .01

Tests of Between-Subjects Effects

Measure: PP

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	2542176987.705	1	2542176987.705	145.083	.000	.879	145.083	1.000
Error	350444780.926	20	17522239.046					

a. Computed using alpha = .01

Estimated Marginal Means

1. Condition

Estimates

Measure: PP

Condition	Mean	Std. Error	99% Confidence Interval	
			Lower Bound	Upper Bound
1	3476.490	300.313	2621.999	4330.981
2	3482.132	280.862	2682.983	4281.281

Pairwise Comparisons

Measure: PP

(I) Condition	(J) Condition	Mean Difference (I-J)	Std. Error	Sig.[a]	99% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-5.642	66.226	.933	-194.077	182.793
2	1	5.642	66.226	.933	-182.793	194.077

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.000	.007[a]	1.000	20.000	.933	.000	.007	.010
Wilks' lambda	1.000	.007[a]	1.000	20.000	.933	.000	.007	.010
Hotelling's trace	.000	.007[a]	1.000	20.000	.933	.000	.007	.010
Roy's largest root	.000	.007[a]	1.000	20.000	.933	.000	.007	.010

Each F tests the multivariate effect of Condition. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .01

2. Time

Estimates

Measure: PP

Time	Mean	Std. Error	99% Confidence Interval	
			Lower Bound	Upper Bound
1	3562.250	284.460	2752.863	4371.636
2	3462.442	285.016	2651.475	4273.408
3	3555.118	303.955	2690.262	4419.974
4	3418.915	287.749	2600.171	4237.660
5	3397.830	293.670	2562.239	4233.420

Pairwise Comparisons

Measure: PP

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	99% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	99.808	48.364	.523	-86.372	285.987
	3	7.131	67.249	1.000	-251.745	266.007
	4	143.334	57.565	.217	-78.263	364.931
	5	164.420	66.699	.229	-92.338	421.178
2	1	-99.808	48.364	.523	-285.987	86.372
	3	-92.677	69.616	1.000	-360.663	175.310
	4	43.526	19.680	.388	-32.231	119.284
	5	64.612	44.651	1.000	-107.273	236.497
3	1	-7.131	67.249	1.000	-266.007	251.745
	2	92.677	69.616	1.000	-175.310	360.663
	4	136.203	76.830	.915	-159.557	431.963
	5	157.289	41.951	.013	-4.204	318.781
4	1	-143.334	57.565	.217	-364.931	78.263
	2	-43.526	19.680	.388	-119.284	32.231
	3	-136.203	76.830	.915	-431.963	159.557
	5	21.086	49.145	1.000	-168.100	210.271
5	1	-164.420	66.699	.229	-421.178	92.338
	2	-64.612	44.651	1.000	-236.497	107.273
	3	-157.289	41.951	.013	-318.781	4.204
	4	-21.086	49.145	1.000	-210.271	168.100

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

Multivariate Tests

	Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Pillai's trace	.547	5.141[a]	4.000	17.000	.007	.547	20.566	.691
Wilks' lambda	.453	5.141[a]	4.000	17.000	.007	.547	20.566	.691
Hotelling's trace	1.210	5.141[a]	4.000	17.000	.007	.547	20.566	.691
Roy's largest root	1.210	5.141[a]	4.000	17.000	.007	.547	20.566	.691

Each F tests the multivariate effect of Time. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

a. Exact statistic

b. Computed using alpha = .01

3. Condition * Time

Measure: PP

				99% Confidence Interval	
Condition	Time	Mean	Std. Error	Lower Bound	Upper Bound
1	1	3555.647	296.124	2713.073	4398.220
	2	3445.683	292.932	2612.193	4279.173
	3	3542.429	337.213	2582.944	4501.913
	4	3400.866	286.148	2586.677	4215.055
	5	3437.825	312.186	2549.551	4326.100
2	1	3568.852	281.783	2767.085	4370.620
	2	3479.200	278.223	2687.560	4270.840
	3	3567.808	289.759	2743.347	4392.270
	4	3436.965	291.078	2608.748	4265.182
	5	3357.834	280.114	2560.814	4154.855

Profile Plots